PB85-199230

Research on Fish and Wildlife Habitat

(U.S.) Fish and Wildlife Service, Leetown, WV

Prepared for

Environmental Protection Agency, Washington, DC

Jul 82

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/8-82/022

2.

3. RECIPIENT'S ACCESSION NO. PB85 199230/AS

4. TITLE AND SUBTITLE
RESEARCH ON FISH AND WILDLIFE HABITAT

5. REPORT DATE July 1982

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
William T. Mason, Jr.

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Fish and Wildlife Service
Leetown, West Virginia

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Office of Environmental Processes & Effects Research
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/16

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This publication contains a series of monographs that discuss and describe computerized habitat management tools and data bases; habitat classification systems; the impact of public policy on habitats and ecosystems; the ecological values of wetlands; progress on research in ecotoxicity; reclamation or restoration of damaged ecosystems; and research needs in the ecosystem and habitats areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)* UNCLASSIFIED

20. SECURITY CLASS *(This page)* UNCLASSIFIED

21. NO. OF PAGES 261

22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

EPA-600/8-82-022
July 1982

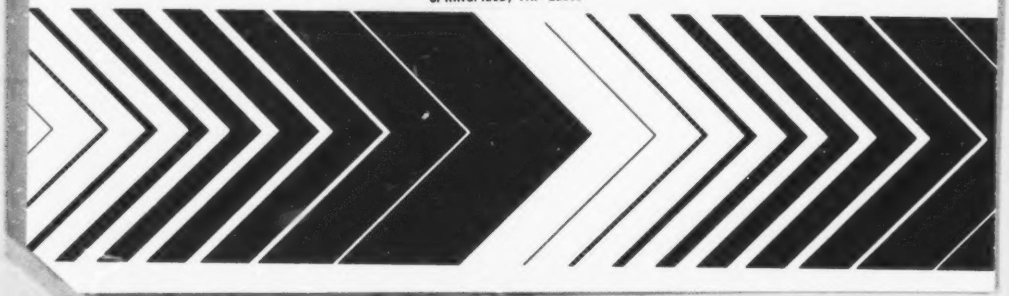
Research and Development

PB85-199230

EPA

Research on Fish and Wildlife Habitat

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161



EPA-600/8-82-022
July 1982

Research on Fish and Wildlife Habitat

Technical Editor

William T. Mason, Jr.
U.S. Fish and Wildlife Service
Leetown, West Virginia

Cousulting Editor

Sam Iker
Chevy Chase, Maryland

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

i.a

DISCLAIMER

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The formation of the U.S. Environmental Protection Agency in 1970 ushered in the first decade of environmental awareness as a total national phenomenon. It was a decade punctuated by major Congressional mandates to restore the nation's waters, to reduce air pollution, and to find a comprehensive approach to other environmental problems—those associated with pesticide use, hazardous waste disposal and toxic substances. It was a decade underscored by the demand for new technology and better science to answer environmental questions and to solve environmental problems.

As the scientific and technical arm of the Agency, The Office of Research and Development is responsible for advancing the state of knowledge about the environment such that critical issues and questions can be addressed and answered effectively, based on the application of state-of-the-art science and technology. In the years since 1970, The Office of Research and Development has produced manifold increases in the data base from which environmental decisions are made and in the sophistication of the understanding which has provided the basis for decisions.

This volume represents our effort to take stock of scientific advances in fish and wildlife habit since the inception of the Agency and to gauge what progress has been made and what remains to be accomplished. The essays in this volume present a range of perspectives on the subject, from the vantage points of the scientific and technical disciplines which have been carrying out relevant research. The points of view represented are varied and sometimes conflicting. But scientific progress depends on just such diversity. The authors at times have speculated about emerging problems and research needs. Such attempts require extrapolation based upon informed scientific judgment. The outcome of that process must, in the final analysis, be recognized as opinion and not fact.

PREFACE

In 1970, the goal of the U.S. Environmental Protection Agency of a clean environment for the Nation was a vast departure from the past decades of thoughtless, unrelenting pollution of our natural resources. The neglect resulted in lakes, streams and estuaries fouled with sewage and industrial wastes, silt laden rivers, municipal point and non-point source discharges and a variety of unsightly trash. However, during the decade of the 1970s signs began to appear that indeed the Nation had taken a different viewpoint towards the environment, and we began to see visible changes in the environment. The steadfast determination of the public leaders, government officials and industry, working in a cooperative atmosphere, resulted in a noticeable improvement in the health and vigor of our biological communities. This monograph "Research on Fish and Wildlife Habitat," produced cooperatively with the U.S. Fish and Wildlife Service, provides insights to research progress during the decade of the 1970s that helped pave the way for a cleaner, more productive environment for the 1980s.

The new national care for the environment, beginning in the 1970s, needs to be nurtured in future decades and will be dependent in large measure on the success of research and development programs in the areas of effective non-point source discharge controls, contaminants clean up, and consideration of habitat development in the planning and management processes. Attention to fish and wildlife habitat research will result in substantial gains for these natural resources during the next decade and will help fulfill the EPA Administrator's role of leadership in major research and demonstration of technology necessary to provide for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the waters of the Nation.

CONTENTS

Page

Foreword iii
Preface iv
Figures vi
Tables x
Fish and Wildlife Habitat and Environmental Protection—An Overview of Research Progress, Allan Hirsch 1
Data Base Development: Overview, Harry N. Coulombe 5
Classification Systems for Habitat and Ecosystems, Robert G. Bailey 16
Species/Habitat Relationships—A Key to Considering Wildlife in Planning and Land Management Decisions, Jack Ward Thomas 27
Design of Computerized Fish and Wildlife Species Data Bases by State and Federal Agencies, Charles T. Cushwa and Calvin W. DuBrock 37
Managing Coastal Ecosystems: Progress Towards a Systems Approach, James B. Johnston 47
Assessment and Prediction of Effects of Environmental Impacts on Fish and Wildlife Habitats: Overview, Kenneth Cummins and Rosanna Mattingly 58
Science for Public Policy: Highlights of Adaptive Environmental Assessment and Management, C. S. Holling 78
Indirect Causality in Ecosystems: Its Significance for Environmental Protection, Bernard C. Patten 92
Understanding the Ecological Values of Wetlands, Joseph S. Larson 108
Instream Flow Assessments Come of Age in the Decade of the 1970s, Clair B. Stalnaker 119
Progress in Research on Ecotoxicity: Single Species Tests (Part 1), Donald I. Mount 143
Progress in Research on Ecotoxicity: Laboratory Microcosm Tests (Part 2), James W. Gillett 150
Mitigation and Management of Damaged Ecosystems or Damaged Habitat: Overview, Robert H. Giles, Jr. 165
WILDMIS—A System for Estimating the Cost to Remedy Habitat Loses, Kenneth R. Russell 170
Wildlife Reclamation of Mined Lands, W. D. Klimstra 183
Reclamation of Wetlands, Mary C. Landin and Hanley K. Smith 195
Ecological Science and Transmission Line Rights-of-Way—A Decade of Innovation, Adjustment and Strain, Jeffrey A. Davis 207
Restoration of Damaged Ecosystems, John Cairns, Jr. 220
Fish and Wildlife Research Needs as Related to Environmental Assessment, Michael D. Zagata 240

FIGURES

Number **Page**

Coulombe

1 – Institutional analyses components in a schematic network of information flow and feedback pathway in the development of ecological information for use in habitat protection 7

2 - Technical analysis components in a schematic network of information flow and feedback pathways in the development of ecological information for use in habitat protection 8

Bailey

1 – Basic systems of the ECOCLASS method, showing the hierarchical classification and possible combinations 18

2 – Third-order ecosystem regionalization of the United States 20

Thomas

1 – The kind and goals of wildlife management 29

2 – The goals, objectives, and process of major kinds of management .. 29

Cushwa & DuBrock

1 – Factors influencing the design of fish and wildlife species data bases 38

2 – Am implementation process for desigining, implementing, and managing a statewide fish and wildlife species data base to meet the information needs of the biologist, resource manager and administrator 40

3 – A wildlife biologist preparing a species description 43

4 – Fish and wildlife species information is retrieved by computer in a cross-index manner to facilitate aggregation of information to aid in planning and management decisions 44

Johnston

1 – Location of coastal ecological characterization studies 48

2 – A wetland energy-circuit model superimposed on a sketch of an emergent wetland 50

3 – Generalized secondary plant succession and associated bird species in white pine (left half) and shrub pine (right half) forests 52

4 – Ecosystem trophic structure and food web 53

5 – Ecological atlas information sources, topics portrayed, and uses of maps 54

Number **Page**

Cummins & Mattingly

1 – Schematic representation of an ecosystem, characterized by balances in all aspects, not by any one in particular 59

2 – Diagrammatic representation of potential interrelationships between species in two communities 60

3 – General illustration of major cycles of the biosphere, which depend on utilization of solar energy 63

4 – The Pass of Faido (a) as sketched by John Ruskin, and (b) as reproduced in etched outline by Ruskin from a drawing by Joseph Turner 69

5 – Predominating areas of concern in ecological problems with which an applied ecologist might have to deal include the above disciplines 70

Holling

1 – Sequence of activities required in analyzing resource systems and devising policies for management 79

Patten

1 – Northern Gulf of Mexico regional ecosystem Nekton submodel (compartments 1-7), with coupling to Plankton (8), Benthos (9), and Organic Complex (environment) submodels 94

Larson

1 – A schematic representation of 6 types of freshwater marsh environments, and their hydrologic regime 109

2 – A cross-section of a typical lacustrine (lake-side) wetland 109

3 – Effect of wetlands on stream flow following a rainstorm 110

4 – A conceptual input-output model for a lakeshore wetland 112

5 – Basic hydrologic characteristics of wetland sites 114

Stalnaker

1 – Legal and institutional events which contributed to increased interest in instream flow 122

2 – Simplified schematic of the logic train and module linkage used in applying the Incremental method 130

3 – Conceptualization of simulated stream reach 134

Mount

1 – A modern aquatic toxicity testing system for hazardous materials 144

Gillett

1 – The system of Metcalf and coworkers mimicking a "farm pond" is used to estimate bioaccumulation potential and biodegradation ... 154

2 – The "terrestrial monoculture" system of Metcalf and coworkers employs a crop grown in soil or vermiculite in a 19-l. carboy and additions of slugs, insects, and a Prairie vole (*Microtus ochregaster*) 157

Number **Page**

3 – The microagroecosystem of Nash and Beall is a large (2 x 1.5 x 0.5 m) monoculture of crop or grass without added fauna 158
4 – Excised soil core microcosms (SCM) have been prepared that are (a) 5 cm (d) x 10 cm (l), and (b) 15 cm x 30 cm 159
5 – The double channel laboratory streams of Warren and Davies have a rock, litter or sediment substrate with water circulated by paddle wheels at each end 161

Giles

1 – Graph of elk population 166
2 – Chart of actions on the land and water 169

Russell

1 – WILDMIS system – components 173
2 – PATREC model for northwest Colorado/northeast Utah – sage grouse habitat evaluation model 177
3 – PATREC potential density calculation form – sage grouse 178
4 – COST EFFECTIVENESS SUMMARY – Strategy – WTRRNGFERT/MMOK – winter range fertilization applied to mountain mahogany – oak scrub (Cercocarpus – Quercus) 180
5 – Detailed cost/strategy Implementation Profile—Strategy – ESTWINTCUR/ANY (establish winter cover in any habitat type 181

Klimstra

1 – A struck-off spoilbank, seeded to *Sericea lespedeza* and orchard grass to establish diversity and openings for wildlife in an area mined in 1940 184
2 – A beaver lodge in a lake resulting from surface mining which was reclaimed through natural revegetation 185
3 – A member of the giant Canadian goose population which was reintroduced to the wetlands of Fulton County, Illinois, through surface mining reclamation in an intensively farmed prime agricultural area 188

Landin & Smith

1 – Sketches of typical east coast and Florida tidal marshes showing plant associations and usual occurrence in the wetlands 200
2 – Sketches of typical Pacific Northwest and California coast tidal salt marshes showing plant associations and usual occurrence in the wetlands 201
3 – Sketches of typical brackish marshes, showing plant associations and usual occurrence in the wetlands 202
4 – Sketches of typical lake or pond and river freshwater wetlands showing plant associations and usual occurrence in the wetlands 203

Number **Page**

Davis

1 – Progressive development of ROW denudation and erosion problems in the Oak-Pine Zone, Long Island, N.Y., due to uncontrolled vehicular access:

- (1a). Before right-of-way 212
- (1b). At completion of right-of-way 212
- (1c). Post right-of-way land degradation 213

Cairns

1 – Modes of action of perturbants on ecosystems 222

2 – Relation of perturbation type with modes of action 223

3 – Diagram to illustrate the meaning of several policy options for management of natural ecosystems 226

4 – Disturbances in general ecosystems create vegetational setbacks and complete recovery is slow, whereas disturbances in perturbation-dependent ecosystems usually stimulate pulses of growth which rapidly decline unless disturbed again 229

5 – Location of the sampling stations on the South Fork and the main stem of the Shenandoah River, Warren County, Virginia 230

6 – Sampling stations on the South River, Virginia for the 1978 biological survey 231

7 – Comparison of macroinvertebrate community diversity ($\bar{d}$) for the 1970 and 1978 South River surveys 233

8 – Comparison of the number of macroinvertebrate taxa collected for the 1970 and 1978 South River Surveys 235

9 – Macroinvertebrate density comparison for the 1970 and 1978 South River Surveys 235

TABLES

Number **Page**

Bailey

1 - Levels of generalization in a hierarchy of ecosystems 19

2 - Basic components and categories of the National Site (Land) Classification System for Renewable Resources 22

Patten

1 - Adjacency matrices for the Figure 1 model 95

2 - Matrices for indirect paths of length 2 in the Figure 1 model 96

3 - Matrices for indirect paths of length 3 in the Figure 1 model 98

4 - Matrices for indirect paths of length 10 in the Figure 1 model 99

5 - Transitive closure matrix for the Figure 1 model of total influence, as summed daily carbon fractions of column compartments, transferred to row compartments over all paths of all lengths 101

Gillett

1 - Chemicals studied in constructed model ecosystems 155

2 - Chemicals studied in excised model systems 156

Russell

1 - Estimated potential population size of eight selected species of wildlife on one oil shale tract in Colorado 175

2 - Ranking of 14 oil shale tracts in Colorado and Utah by mountain blue-bird nesting habitat quality according to PATREC results, September 1979 176

Cairns

1 - Mean number of organisms for unstressed and stressed areas for the 10 surveys from 1972 and 1977 232

2 - Mean annual flow, zinc, BOD_5, for AVTEX's effluent from 1972 to 1977 233

3 - Description and location of the 12 sampling sites for the 1978 biological survey 234

4 - Improvements in du Pont's waste treatment system since 1970 236

FISH AND WILDLIFE HABITAT AND ENVIRONMENTAL PROTECTION— AN OVERVIEW OF RESEARCH PROGRESS

Allan Hirsch

Protection of fish and wildlife resources is an important concern in regulating environmental pollution. Publication (in 1962) of Rachel Carson's[1] *The Silent Spring*, which eloquently described the effects of improper pesticide use on wildlife populations, was a harbinger of the environmental movement of the following decade. Federal and state water quality criteria and standards have embodied a concern for protecting aquatic life as well as public health and other values. This concern has been central to the evolution of the national water pollution control program. The impact of the Torrey Canyon, first of the major oil spills of the supertanker era, was measured in terms of its effects on coastal ecosystems, fisheries and marine bird populations. Since then, the oiled seabird has continued to be a visible symbol of oil pollution.

Fish and wildlife protection is provided for in key legislation administered by the Environmental Protection Agency (EPA). For example, the objective of the Clean Water Act (ee U.S.C. 466 et seq.) is "...to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Act states as a national goal "...water quality which provides for the protection and propagation of fish, shellfish, and wildlife." Other portions provide for the protection of wetlands, reflecting the importance of wetlands for fish and wildlife as well as other values.

The Toxic Substances Control Act (15 U.S.C. 2601) and the Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. 136 et seq.), designed to regulate the use of toxic chemicals which have an impact on the environment, both make provision for the protection of fish and wildlife as well as for the public health. The Clean Air Act (42 U.S.C. 1857 et seq.), in its requirements relating to "Permissible Significant Deterioration" of existing air quality, specifically protects Class I areas such as National Parks and National Wildlife Refuges. The most recent major environmental legislation is the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 U.S.C. 9601) which deals with disposal of hazardous wastes. Known as "Superfund," it provides for compensation of claims for damage to natural resources, including restoration costs.

In administering these and other legislative mandates, EPA has established as broad goals the protection of public health and sensitive ecosystems. These goals are complemented by those of other environmental legislation such as the National Environmental Policy Act (16 U.S.C. 661-666), the Endangered Species Act (16 U.S.C. 1531-1543), and the Surface Mining Control and Reclamation Act (30 U.S.C. 1201). All contain important provisions involving the protection of fish, wildlife, and related ecosystems from environmental impacts.

The Author: Dr. Allan Hirsch is Director, Office of Environmental Processes and Effects Research, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. In 25 years of public service, he has maintained leadership in developing new ways of addressing natural resources planning. His former position was Chief, Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C.

This body of legislation reflects the great importance society places on preserving the cultural, recreational and commercial values of fish and wildlife resources. Pollution and loss of habitat are now widely recognized as key determinants in maintaining those resources. For example, the impact of acid rain on fisheries resources of lakes in Scandinavia and northeastern North America has emerged as a pollution control question of major international importance. In its first State-of-the-Parks report issued in 1980, the National Park Service[2] reported on a survey which identified and characterized threats that endanger natural and cultural resources of the national parks. The survey concluded that environmental threats from outside of the parks, such as air and water pollution, were as significant to the future protection of park ecosystems as the more traditionally recognized internal impacts associated with heavy visitor use.

On a positive note, pollution abatement has been closely linked to the successful restoration of the Atlantic salmon fishery in the Connecticut River and other New England streams. The role of DDT in the decline of peregrine falcon, bald eagle, pelican, and other bird populations, and the subsequent recovery of these populations following the ban on DDT in the U.S. is well-known.

In addition to their intrinsic value and their contribution to the quality of life, fish and wildlife often have a direct relation to public health. Contaminants accumulate in the food chain and the public is exposed, particularly through the ingestion of seafood. Sometimes biomagnification has disastrous consequences, such as the outbreak of "Minamata Disease" in Japan, which was associated with mercury contamination of seafood products. Fish are often contaminated with metals and chlorinated hydrocarbons and cannot now be safely harvested in many areas.

Recent research on polychlorinated biphenyls (PCBs) in Great Lakes food chains highlights this complex issue. PCBs accumulate in fish tissue, and consumption of contaminated fish has been identified as a major route of human exposure to this chemical in the Great Lakes region. Based upon measurements of PCB levels in various components of the environment, it has been estimated that consumption of one pound of Great Lakes trout would provide the same exposure as five years of breathing ambient air and drinking local water. Further, preliminary studies in Michigan have indicated that levels of PCBs in human blood samples were in direct proportion to the amount of fish consumed.[3]

Fish and wildlife are sometimes referred to as barometers of environmental quality. Biomonitoring is a valuable tool for assessing the overall buildup of contaminants in the environment. Aquatic organisms can also play an important role in screening effluents and chemical mixtures for toxicity. EPA has sponsored development of a marine monitoring system called *Mussel Watch* in which mussel tissue is analyzed to assess the buildup of contaminants in the marine environment.

On a more speculative note, a report of the National Science Foundation[4] on long-term ecological measurements identified seabird populations as potentially important indicators of marine environmental quality. Marine birds are long-lived and widely dispersed much of the year but highly concentrated during their nesting season. They are thus amenable to reasonably accurate statistical sampling. Because they are high in the food chain, they are potential accumulators of contaminants as well as integrators of ocean ecosystem conditions. It might be feasible to design long-term sampling programs that combine reliable monitoring of nesting areas through aerial photography, species composition studies, and sampling of tissue and eggs for contaminants, as a way of detecting widescale environmental changes in the oceans. Seabirds might thus be used to meet a recognized need for an early warning system to detect potential contamination of the oceans.

The importance of maintaining life support systems and genetic diversity is likely to receive increased scientific recognition during the coming decade. This is best expressed in the recently issued World Conservation Strategy prepared by the International Union for the Conservation of Nature and Natural Resources[5] and commissioned by the United Nations Environment Program. The strategy states three main objectives of living resources conservation:

- To maintain essential ecological processes and life-support systems (such as soil regeneration and protection, the recycling of nutrients and the cleansing of waters) on which human survival and development depend.
- To preserve genetic diversity (the range of genetic material found in the world's organisms), on which depend the functioning of many of the above processes and life-support systems, the breeding programs necessary for the protection and improvement of cultivated plants, domesticated animals and microorganisms, as well as much scientific and medical advance, technical innovation, and the security of the many industries that use living resources.
- To ensure the sustainable utilization of species and ecosystems (notably fish and other wildlife, forests, and grazing lands), which support millions of rural communities as well as major industries.

The monograph that follows reflects the research progress of the last decade. It describes information and methods which can assist in effective environmental management and in protection of the values described in the World Conservation Strategy. Traditionally, debates concerning conflicts between economic development and protection of fish and wildlife resources have been characterized more by extreme polarization than by discussion based upon analysis and clear display of the tradeoffs involved. Opposing advocacy views will always play a major role in such issues. However, the conflicts in many cases could be narrowed by applying methods such as those described in this report (despite the fact that the natural variability and complexity of ecosystems make quantitative prediction inherently more difficult than for some other elements of the equation).

Perhaps a milestone in the growing recognition of the need for improved assessment was the environmental analysis related to construction of the Trans-Alaska Pipeline. The dearth of quantitative and analytical data on fish and wildlife impacts stood in stark contrast to more quantifiable information on hydrologic, geologic, and other environmental factors. This triggered major study efforts to supply much of the missing information, which in turn led to incorporation of various protective measures in the pipeline design.

The energy crisis has seemed to accelerate recognition of the need to develop assessment capabilities. Such assessments reflect a realization that while energy development is inevitable in many valuable fish and wildlife habitats, adverse impacts can be minimized if environmental values are adequately addressed in the planning stages of development. Indeed, in some areas, development can deliberately or inadvertently enhance fish and wildlife habitat. In some midwestern coal regions, for example, the broken terrain, ponds, and vegetation associated with abandoned strip mine lands provide islands of ecological diversity in areas otherwise dominated by monotypic agriculture. Other examples are the creation of artificial wetlands in connection with phosphate mining or of shorebird breeding areas with dredge spoil.

The contents of this monograph deal heavily with physical disruption of habitat as well as with subject matter more traditionally associated with environmental pollution (such as ecotoxicology). Many of the developments affecting fish and wildlife habitat involve both physical and chemical modifications—mining, water resource development, and energy resource development are examples. To assess the impacts of such developments, it is necessary to take into account both modification of physical habitat features and chemical contamination.

The relationship between environmental contamination and the natural features that define habitat value also needs much more attention. For instance, it would make little sense to establish water quality standards and pollution abatement programs designed to protect well-balanced fish populations if the receiving streams were inherently unsuitable to support such populations, either because of physical disruption such as stream channelization and the loss of riparian habitat or because natural background characteristics limited aquatic life.

The review of research progress on habitat protection presented in this monograph provides glimpses of research and technical development during the last decade. The articles range from the broadly conceptual and theoretical to the practical. The review addresses three major themes: (1) development of data bases on the characteristics of ecosystems or wildlife populations and on the critically important definition of species/habitat relationships; (2) means of assessing and predicting effects of human modification of ecosystems on fish and wildlife resources; and (3) means of mitigating or managing damaged ecosystems and habitat.

In summary, applied research on fish and wildlife habitat has resulted in significant advances during the last decade that can contribute to sound environmental management during the coming decade. As is often the case with research advances, application still lags behind development of many of the concepts discussed in this document. It is paradoxical that although concern for ecological values is the central theme of the National Environmental Policy Act, biological and ecological analysis continues to be the weakest element of the environmental assessment process. Increasingly, however, many of the new assessment approaches are being applied and, through application and testing, are enhancing our understanding and our ability to make our effective management choices.

REFERENCES

1. Carson, R. 1962. *The Silent Spring*. Fawcett Publishing Co., New York, NY.
2. U.S. Department of the Interior, National Park Service. 1980. State of the Parks 1980, Report to the Congress. Washington, D.C., 44 pp.
3. Swain, W. (In press). An ecosystem approach to the toxicity of residue forming xenobistic organic substances in the Great Lakes. Manuscript submitted to Environmental Studies Board, National Research Council, National Academy of Sciences. Washington, D.C.
4. National Science Foundation. 1977. Long-term ecological measurement. Report of a conference. Woods Hole, Massachusetts, March 16-18, 1977. Washington, D.C., 26 pp.
5. International Union for Conservation of Nature and Natural Resources. 1980. The world conservation strategy. Gland, Switzerland.

DATA BASE DEVELOPMENT:OVERVIEW

Harry N. Coulombe

DATA BASES AND HABITAT PROTECTION

The seventies generated a national—even an international—awareness of the importance of environmental quality to humanity. It was recognized that environmental quality included living space for the creatures that share our planet, not only for reason of their intrinsic value, but for the necessary function wildlife serves in the biosphere man's life support system.

In the seventies, it was recognized that a technological explosion had resulted in encroachments upon the living space of fish and wildlife. In the United States, a flood of legislation directly or indirectly called for information on the status and trends of fish and wildlife and/or their habitat.[1]

It became necessary to consider the impacts of proposed land use changes, resource management practices, energy development, and other expansions of technology on fish and wildlife resources and habitats. These new requirements highlighted the growing problem associated with gathering and organizing available knowledge on the relationships between wildlife or fish and their living space requirements—that of the short time frames in which decisions affecting wildlife had to be made against the backdrop of other public needs and values. The critical need for rapid methods of assessing impacts upon wildlife became apparent, and the search for timely, effective, and efficient approaches to this problem has taken many forms.

In its broadest sense, a data base is any organized, systematic means of quickly accessing data or information. It also provides a framework in which new data, collected through accepted scientific means, can be stored. The traditional data base of the professional resource manager has been personal files, accumulated textbooks and technical papers, and perhaps similar resources belonging to one's staff or colleagues. In the seventies, a plethera of paper (sometimes inundating the resource manager) appeared; a trend toward automated data storage and retrieval and a rapid development of inexpensive digital computing capabilities also occurred. The organization and integration of existing data or previously collected information is the theme of this section.

Virtually every paper in this monograph explicitly or implicitly deals with some level of data base development. The papers selected for this section are intended to give some glimpses of the scope of activities already underway in the eighties. Robert Bailey deals with the process of classification (organizing data and information into units), which is basic to human logic. Jack Ward Thomas' paper describes the integration of the relationship between wildlife living requirements and, the "multiple use" mandates of major federal land use management agencies. Charles Cushwa provides a perspective on the efforts to develop data bases, for wildlife species, that are national in scope and supportive of a broad range of habitat

---

The Author: Dr. Coulombe has held academic positions in the Institute of Arctic Biology, University of Alaska, and the Ecology Program, San Diego State University, for six years, where he became Program Manager for the Center for Regional Environmental Studies. For the past six years, he has been an administrator with the U.S. Fish and Wildlife Service's Western Energy and Land Use Team.

protection uses. James Johnston describes the approaches being undertaken to integrate a large number of data sets into an ecosystem framework for the support of habitat protection activities in the coastal areas of our nation. Many other representative endeavors could have been included here, particularly freshwater or aquatic data base development.

During the late sixties and the 1970s another revolution was occurring in the area of ecology, in which step-down investigation began to give way to synoptic integration and the emergence of holistic concepts of ecological systems.[2] Although recognized as a discipline within the broad framework of biological sciences since the 1930s, the conceptual basis for the ecosystem as a fundamental unit of the biosphere has only recently been drawn into perspective.[3] This strengthened concept rapidly infiltrated applied ecology—in wildlife management, forest and range management, and other aspects of natural resource management.[4] Collectively, current ecological concepts have brought a new perspective to dealing with the problems and processes of habitat protection. Indeed, the holistic approach to management problems has furthered the need for information relating species and their habitat requirements to ecological processes.

The impact of all the changes of the seventies on the field resource manager has been staggering. Keeping up—with current legislation, regulations and policy, the new concepts in his field, the enormous volumes of paper, and the mixed blessings of modern computing—is a full-time job in itself. At the same time, the press of day-to-day decisions affecting the fate of the resources he or she is charged with conserving leads to increased reliance on one's best professional judgment. On the other hand, society has developed an almost mystical belief in its own technology, including the sometimes sterile information generated using computers. All too often a resource manager's professional judgment is questioned before our judicial system, and the desire for extensive documentation of data and methods becomes an issue unto itself.[5]

Two major issues permeate all data base development activities, present and future: 1) What is the appropriate role of data bases in development of information to support the governmental decision processes that have an impact on habitat protection? and 2) Where are we headed in our attempts to develop integratable information bases to support habitat management?

THE ROLE OF DATA BASES IN INFORMATION DEVELOPMENT

During the late 1970s the developers and suppliers of natural resource technical information recognized that their products had to fit the needs of the decisionmakers.[1] [6] These specified information needs are constrained by institutional as well as scientific/technical limitations. It is helpful to define the relationships used to develop specific ecological information needs. Ecological information development is not limited to, but includes all aspects of habitat protection. The determination of institutional and scientific/technical opportunities and constraints can be schematically depicted as an information flow network, which has two primary sets of components—institutional analysis of governmental decisionmaking and technical analysis of the concepts guiding data base development. These two sets are briefly defined and discussed below from a generalized federal decision process perspective.

Institutional Analysis Components

Institutional analysis components are the primary drivers in a schematic network of information flow and feed-back pathways in the development of ecological information for use in habitat protection (Figure 1). Legal mandates (laws, regulations, executive orders, court decrees), together with program needs determine Study Criteria, which transmit specifications to the Technical Analysis Components (Figure 2) for further processing.[1] The production of the specified information

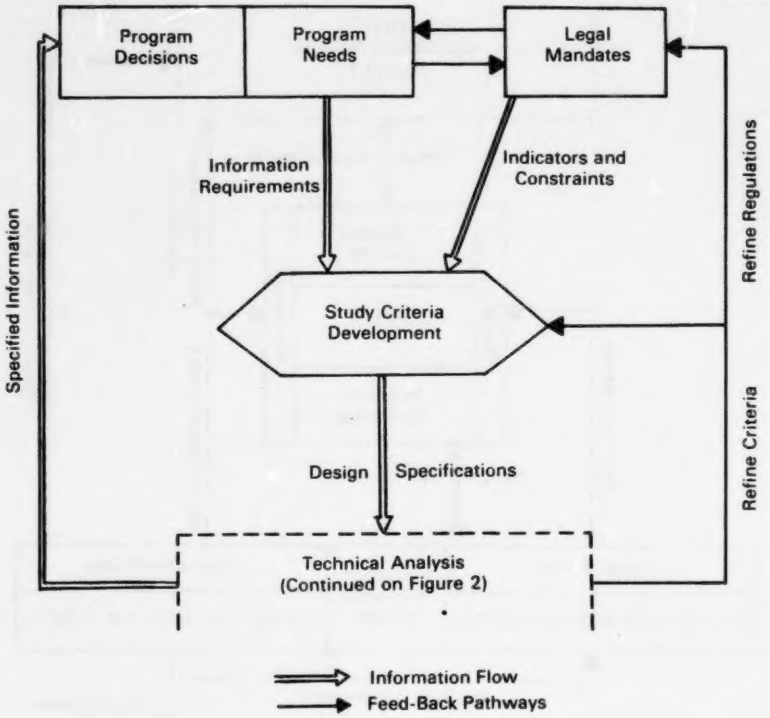


Figure 1. **Institutional analysis components in a schematic network of information flow and feedback pathway in the development of ecological information for use in habitat protection. Legal mandates (laws, regulations, executive orders, court decrees), together with program needs (such as Coal Management or Renewable Resource Assessments) determine Study Criteria, which transmit specifications to the Technical Analysis Components (Fig. 2) for further processing. The production of the specified information through technical analysis steps feeds Program decisionmaking.**

through technical analysis steps feeds Program decisionmaking. Let us explore these components a little further.

Laws, regulations, court decisions, and executive orders provide guidance on the scope and focus of public interest. Federal *Programs* (such as Coal Management) are used to implement *Legal Mandates*; program action decisions (such as tract leasing) define the specific information needed. The papers in this section and the rest of the monograph describe selected examples of both Legal Mandates and Program Needs. The last component of the institutional segment can be called *Study Criteria Development*. Inputs from legal mandates include general and (occasionally) specific indicators. Such inputs can be considered classes of variables to track as information output.[1] Constraints are inputs from both legal mandates and program needs. They take various forms such as agency responsibilities, geographic scope, timing of outputs or actions, or fiscal and manpower limitations.

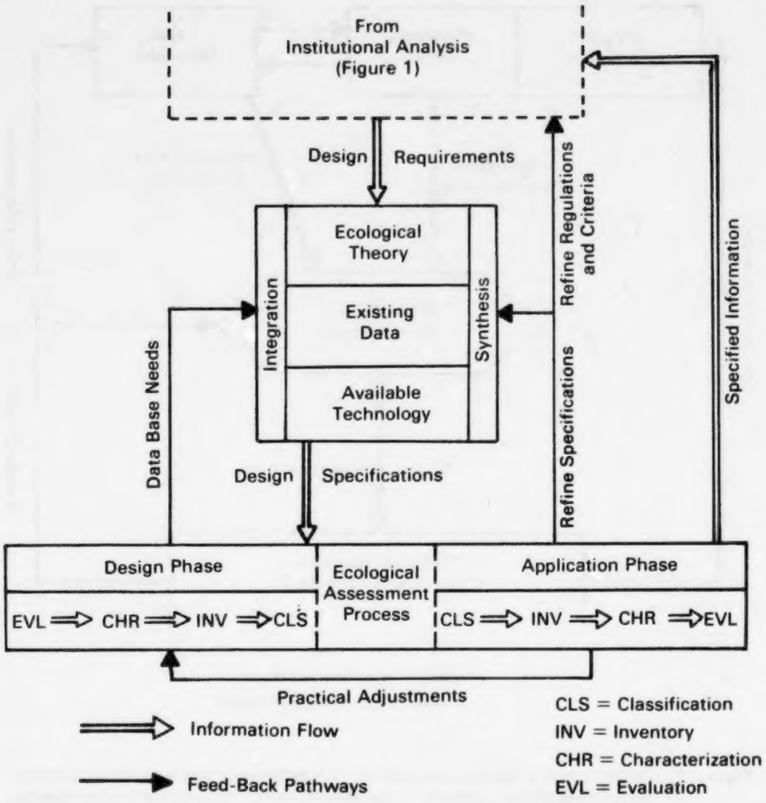


Figure 2. Technical analysis components in a schematic network of information flow and feedback pathways in the development of ecological information for use in habitat protection. The input of design requirements from institutional analysis (Fig. 1) drives the technical analysis components. An important step is the integration and synthesis of ecological theory, existing data, and available technology (for obtaining new information) into design specifications for the ecological assessment process. It is important to note that the four general steps of assessment (Classification, Inventory, Characterization, and Evaluation) are designed in reverse sequence of their application, in order to insure efficient and effective delivery of the specified information required for decisionmaking.

The synthesis of the indicators, constraints, and program needs produces the *Study Criteria*. It must be recognized that assumptions are frequently made to define the variables of interest (indicators) and programmatic information requirements (scope, resolution, precision, and accuracy) operationally. Secondly, differing requirements must be determined for information targeted for several different levels of decisionmaking. Collectively, this synthesis produces outputs that can be termed *Design Requirements*. The nature of these design requirements then trigger any or all of several technical subsystems: technological assessment; socio-economic-political assessment; and ecological assessment. Environmental assessment may be considered the integration of the information from these subsystems for the purpose of

managing ecological systems for man's benefit and survival.[3] Another process which should be a part of this information network is ecological monitoring.[7] This requires the repetitive application of the ecological information development process on key elements defined in the initial assessment.

Technical Analysis Components

The input of design requirements from institutional decision process analysis (Figure 1) drives the technical analysis components (Figure 2). An important step is the integration of ecological theory, existing data, and available technology for obtaining new information into design specifications for the ecological assessment process. It is important to note that the four general steps of assessment—Classification, Inventory, Characterization, and Evaluation—are designed in reverse sequence of their application in order to insure efficient and effective delivery of the specified information required for decisionmaking.

The synthesis which results in the output of design specifications provides specific technical requirements and scientific rigor to the design phase of the ecological assessment process. Ecological assessment processes are often initiated without the application of this step in the process. When ecological assessments are based on the study criteria alone, the decisionmaker is usually provided with irrelevant as well as scientifically unsupportable analyses. For example, in the Department of the Interior (as elsewhere) this has resulted in the writing of voluminous Environmental Impact Statements designed to meet the requirements of the National Environmental Policy Act of 1969 (NEPA), and Program Decision Option Documents designed to be used by the actual decisionmakers.[1]

The ecological assessment process may be defined as integrating the systems of classification, inventory, characterization, and evaluation. The application of this process, through decisionmaking, results in an analysis of the state of a resource, its direction of change, and its significance to society. The definition of the four subcomponents is as follows:[1]

Classification

a. The process of developing a system for grouping real entities into categories. (For example, the Linnaean taxonomic classification for plants and animals.)

b. The process of developing a system of categories based on attributes of real entities. (For example, the range condition classes used by several federal agencies.)

Inventory

a. The process of measuring attributes of an ecological system and its components in a particular geographical area. (For example, delineating and measuring the plant species composition of a stand of vegetation.)

b. The identification of which category in a classification system an entity is a member of, based on (a). (For example, determining the habitat type of the stand vegetation based on species composition.)

c. The results of applying (a) and (b).

Characterization

a. The process of describing the ecological systems in a given geographical area, derived from analyses of such ecological relationships as interactions, dependencies, and co-occurrences. (For example, primary data analyses to estimate the current population size and productivity of an elk herd.)

b. The results of (a).

Evaluation

a. **The process of integrating and interpreting characterizations with aspects of other ecological and environmental perspectives and the reforming of the** resultant information to meet specific requirements of a decision process (synthesis). (For example, secondary data analyses such as predicting future changes in elk numbers due to increased logging activity and/or cattle grazing.)

b. The process of translating characterization or synthesis into human values, either social or economic (interpretation). (For example, expressing the predicted future elk numbers as changes in harvest success rate or dollars generated by elk hunting.)
c. The results of (a) and/or (b).

These component processes are linked together through what may be termed *information management systems*; the assessment outputs (specified information) are generally ecological opportunities, constraints, and the prediction of risks.[1,6] These outputs, when integrated with the results of other assessment processes, form the basis for program decisionmaking. The resulting decisions, in a planning context, may trigger repetition of the schemes shown in Figures 1 and 2, with increasing resolution on smaller subsets of the initial geographical area considered.

The need for a basic understanding of the relationship of information flow between the four subcomponents of ecological assessment (classification, inventory, characterization, and evaluation) and the two phases (design and application—Figure 2) is emphasized. Recent experience in the design phase indicates the need to repeat the obvious logical dictate: analysis requirements (evaluation and characterization) must be the primary driver for data collection and organization specifications (inventory and classification).

The role of data base development primarily centers on the integration of *Existing Data* and *Ecological Theory*, as for readily available input into the *Characterization* and *Evaluation* steps in ecological assessment. The requirements and specifications for *Classification* are inseparable from this step-wise view of ecological assessment, and, hence, data base development.

WHERE ARE WE HEADED?

Institutional Perspective

The convergence of natural resource conservation legislation and broadened mandates to protect public health and welfare began in the late 1950s and 1960s. The earlier conservation ethic placed man and his social activities apart from nature. The evolution of this ethic into the environmental movement of the sixties forced a recognition of man's dependence on his environment. Thus, environmental quality was increasingly considered to be an important attribute of the public welfare. The underlying terms of early federal legislation reinforced this assumed separation between man and nature. The public's concern for the protection of environmental quality, which had previously been applied principally to federal water construction projects, was given universal application throughout the federal establishment by NEPA (42 U.S.C. 4321). NEPA represented a convergence of legislation concerned with natural resource conservation with that involving public health and welfare; NEPA set the tenor and policy basis for subsequent federal and state environmental **lesiglation.**[1,6]

In the 1970s, Congress, various federal agencies, and the courts were eager to infuse nearly every facet of federal and private activity with the mandates of NEPA. The NEPA mandate also led to revision and updating of previous environmental legislation, notably the Water Resources Planning Act of 1965 (42 U.S.C. 1962) and the Fish and Wildlife Coordination Act (16 U.S.C. 661-666). The proliferation of federal environmental conservation legislation and regulations during the 1970s was unparalleled. Some of the more prominent mandates were: The Water Resources Council's Principles and Standards (38 FR 24778: 1973), Federal Water Pollution

Control Act Amendments 1972 and 1977 (33 U.S.C. 466 et. seq.), Endangered Species Act of 1973 (16 U.S.C. 1531-1543), Clean Air Act of 1974 as Amended (42 U.S.C. 1857 et. seq.), Federal Nonnuclear Energy Research and Development Act of 1974 (42 U.S.C. 5901-5915), Forest and Rangeland Renewable Resources Planning Act of 1974 (16 U.S.C. 1601), National Forest Management Act of 1976 (PL94-588), Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701-1781), Soil and Water Resources Conservation Act of 1977 (16 U.S.C. 2002), and the Surface Mining Control and Reclamation Act of 1977 (30 U.S.C. 1201).[1,6]

All of these mandates address the protection, inventory, conservation, rehabilitation, or planning of the nation's environmental resources. Many of these statutes represent the organic legislation of federal agencies such as the Environmental Protection Agency, the Water Resources Council, the Council on Environmental Quality, the Bureau of Land Management, and the Office of Surface Mining, all of which contribute to habitat protection. For a compilation of relevant federal laws the reader is referred to Ross[8] (prior to 1972) and the U.S. Fish and Wildlife Service.[9] Most of the recent legislation is focused on species/populations, biological integrity, environmental values, or habitat, all of which may be dimensions of habitat protection. Some important common elements of these laws are:

- The objective projection, within the environmental impact assessment, of the quantitative and qualitative changes in the physical, chemical, biological, and social structures associated with those alternative ways of achieving the proposed objective. The "goodness" or "badness" of each alternative is determined by the decisionmaker(s) and is not made a part of the assessment.
- The recognition that man can exploit natural resources to a point where his life support system may begin to break down. They also recognize and reaffirm the NEPA goals that modern industrialized society must legally provide for the maintenance, conservation, and/or rehabilitation of its basic life support system, for both present and future generations. The environmental assessment should determine the long-term as well as the short-term changes of the alternatives and give particular attention to irreversible, unavoidable, and unmitigatable impacts.
- The capability to quantify the extent and status of natural resource components, their functional interrelationships, and their susceptibility to irreparable damage or loss.
- The capability to accurately predict the effects on, or losses of, natural resources resulting from man-induced changes.
- A recognition of the interactions between physical, chemical, and biological components and their relationship to environmental quality. Thus, to varying degrees, an ecosystem approach to impact assessments is defined.

None of the environmental laws or regulations which require impact assessment prescribe a specific methodology to be used in the collection, compilation, analysis, or evaluation of natural resource information. The common elements provide general guidance in approaching the question of how to design an assessment methodology and thus the role and requirements for data base development. These legal mandates will evolve and become refined, and some new policies will be added.[10] A major opportunity for a common theme or approach to impact assessments in the coming decade is related to the ecosystem concept.

Technical Perspectives

The ecosystem concept can be applied at both a conceptual and an operational level in ecological assessments.[3] The ecosystem represents the top of an operationally definable hierarchy of levels of biological integration, followed by subsystems (communities), system components (populations), and component elements (individual organisms). Inherent in this hierarchy are the interactions and relationships between and within the various levels. However, these attributes are often neglected when an assessment is made,[2] in part because of the gap between accepted knowledge at the level of individual organisms and knowledge of their relationships at the community or ecological subsystem level.[11] A useful synthesis of ecological theory that begins to bridge this gap is "An Ecosystem Paradigm for Ecology."[3] For most practical purposes, the spatial boundaries of ecosystems can be defined by various levels of integration of physical properties, in a hierarchial fashion. This approach to classifying and delineating ecosystem units is discussed in Robert Bailey's chapter; this concept represents a cornerstone for the progress to come in the 1980s.

Within the framework of the ecosystem, the ecological concepts that can provide a starting or focal point for practical assessment design are numerous and diverse. Four common approaches are: (1) habitat space; (2) ecological niche; (3) evolutionary; and (4) functional.[1] The chapters that follow in this section demonstrate several applications of these conceptual approaches, sometimes in various combinations.

The habitat space approach is defined as the analysis of species distributional relationships to environmental (biotic and abiotic) factors.[3,12] *The ecological niche approach* can be described as going beyond "where an organismic unit is found" to "what the organismic unit does" in the context of the ecosystem.[12] A combination of these two approaches has been developed to ecologically characterize regional landscapes in response to programmatic needs of the new Federal Coal Management Program.[13] Charles Cushwa's paper discusses several data base development efforts that focus on the habitat space concept.

The evolutionary approach is the identification of the adaptive strategies of the various species of an ecosystem and the selective forces that account for these strategies.[14] Implicit in this approach is that for each set of environmental conditions there is a bioenergetic benefit and cost to the various structural and functional relationships a species can adopt.[14] Further, evolutionary selection tends to produce (but not necessarily perfect) adaptation to complex and sometimes conflicting environmental problems.[3,15] Jack Ward Thomas discusses in his paper a combination of the ecological niche and evolutionary approaches developed by the Forest Service in eastern Oregon.

The functional approach may be defined as the analysis of the properties of energy and material exchange in ecosystems, and the study of the behavior of ecosystems under stress or perturbation.[3] This is a broad description intended to include more than energy budgets and systems modeling.[2,14] The study and analysis of ecosystem function was essentially born in the late sixties and the seventies; it should mature in the coming decade. The development of coastal characterizations presented in James Johnston's chapter introduces elements of the functional approach, blended with aspects of the previous three concepts.

Comprehensive ecosystem analysis must blend each conceptual approach, with proper linkages, to obtain refinement and substantiation of an integrated theory. The translation of this integrated theory into the applied world of ecological assessment is a major challenge of the decade ahead. Certainly the design requirements (Figures 1 and 2) can provide guidance as to the proper amount of each conceptual approach required for a specific assessment need.

Most real world ecological assessment designs result in the layering of several relatively independent ecological assessment processes, with little if any real integration.[2] A structured approach to matching conceptual frameworks to appropriate methods and problems solution, (e.g., the development of strategies for ecological assessment) is lacking; indeed, it has been said to be nonexistent.[16] Especially in the public arena, the decisionmaking procedure called "*successive limited comparisons*," which tends to produce *incremental policy change*,[17] fosters the practice of iteratively defining and applying ecological assessments. Perhaps in the coming decade, we will see greater support for comprehensive planning for ecological assessments. This should foster the appropriate role for data bases that can serve several purposes in the decisionmaking arena. Certainly, recent legal mandates lead in this direction (see discussion under Institutional Perspectives).

It has also been suggested that the central issue in applying ecological concepts in environmental science is how to cope with the unknown, *not* how to mobilize our present knowledge to best advantage.[18] Further, the need to document assumptions, doubts, and tradeoff considerations used in executive branch decisions is fundamental to the judicial branch's responsibilities.[5] The emergence of the "Adaptive Environmental Assessment and Management" approach offers an attractive solution to the pragmatic design of ecological assessments.[19] This approach has been applied to a wide variety of environmental and natural resource problems (see C.S. Holling, Section II). As with any methodology, not all applications have been successful for both institutional and technical reasons.[20] Other approaches offering methodologies for consideration have emerged in the seventies. These are: the integration of social and technical approaches;[21] combined assessment of components, structural features, and functional indicators;[22] and the systems approach in assessment design.[23] All of these newer approaches bring a different perspective to the nature and role of data bases.

Perhaps the most striking feature of virtually all ecological assessments during the past decade is the absence of learning—the feedbacks to the steps in design (Figures 1 and 2). The role of feedback is essential to both corrective policy changes and improved predictions of important aspects of the ecological system susceptible to failure. This "safe-failure" philosophy has not yet infiltrated basic legal mandates but is being incorporated into agency policy through revised implementation regulations,[24] which is a trend that hopefully will be followed in the ensuing decade. The tendency has been to treat environmental assessment requirements as a one-time step (or hurdle); thus, too little emphasis has been placed on the role of monitoring key ecological factors.[7] A basic problem has been the lack of legal or institutional mandates to require or conduct such follow-through. Recent legislation, such as the Surface Mining Control and Reclamation Act of 1977, and its subsequent implementing regulations issued by the Office of Surface Mining Reclamation and Enforcement, USDI, begin to address this issue and will help provide incentive for ecological monitoring as we enter the 1980s.

CONCLUDING REMARKS

From the foregoing discussion, I have presented several perspectives on the role of data base development and our direction in the coming years. There is clear legal mandate to pursue data base development from an ecological perspective, focused upon ecosystem planning and management. Several technical challenges are apparent as we look to the future. Certain bridges need to be built between ecological theory and the design of assessment procedures. Common information requirements need to be sought among federal, state and local agencies, in order to reduce the number of data bases that need to be developed. Collectively, these challenges define a role for the development of ecological data bases to increase the effectiveness and efficiency of assessments for various purposes.

Perhaps the greatest challenge is to modify the institutional perception that assessments (such as NEPA) are not a technically separate process from monitoring the effects of a decision. Such follow-through not only fine tunes assessment process predictive capabilities but also keeps the resource manager advised of unexpected ramifications of that decision. Thus a major role emerges for the development of ecological data bases—the linkage of measurements through time (and space) for the detection of change. Subsequent interpretation of ecological change is the key to managing healthy ecosystems for man's use and benefit.

REFERENCES

1. Coulombe, H. N., L. S. Ischinger, D. A. Asherin, and J. G. VanDerwalker. 1980. Application of ecological theory to environmental assessment in the planning of western energy development. *In* Proc. of AIBS/ESA Symp. Energy and Ecology in the West. Aug. 5, 1980, Tucson, Ariz. U.S. Environmental Protection Agency, Washington, D.C.
2. Odum, E. P. 1977. Emergence of ecology as a new integrative discipline. Science. 195:1289-1293.
3. Johnson, P. L., ed. 1977. An ecosystem paradigm for ecology. ORAU-129. Oak Ridge Associated Universities. Oak Ridge, Tenn.
4. Van Dyne, G. M., ed. 1969. The Ecosystem Concept in Natural Resource Management. Academic Press. New York, N.Y.
5. Bazelon, D. L. 1980. Science, technology and the court. Science. 208: editorial, 16 May 1980.
6. Coulombe, H. N. 1978. Toward an integrated ecological assessment of wildlife habitat. pp. 5-23. *In* H. G. Lund, ed. Integrated inventories of renewable natural resources: Proc. of workshop, January 8-12, 1978, Tucson, Arizona. General Technical Report RM-55. Rocky Mountain Forest and Range Experiment Station. Forest Service, USDA. Fort Collins, Colo.
7. Council on Environmental Quality. 1980. Interagency task force report on environmental data and monitoring. Report PB80-184039. National Technical Information Service, U.S. Department of Commerce. Springfield, Va.
8. Ross, J. E., ed. 1975. A compilation of federal laws relating to conservation and development of our nation's fish and wildlife resources, environmental quality, and oceanography. Stock number 052-070-02971-4. U.S. Government Printing Office.
9. U.S. Fish and Wildlife Service, 1980. Ecological Services Manual 101. Habitat as a basis for environmental assessment. Fish and Wildlife Service, USDI. Washington, D.C. National Technical Information Service No. PD-81-1188443.
10. U.S. Department of Agriculture. 1979. Future challenges in renewable natural resources. Proc. of a national workshop, Jan. 22-25, 1979, Rosslyn, Virginia. USDA Misc. 1376. Washington, D.C. 116 pp.
11. Orians, G. H. 1980. Micro and macro in ecological theory. BioScience 30(3): 79.
12. Odum, E. P. 1971. *Fundamentals of ecology*. 3rd Edition. W. B. Saunders Company. Philadelphia, Pa.
13. Asherin, D. A., H. L. Short, and J. E. Roelle. 1979. Regional evaluation of wildlife habitat quality using rapid assessment methodologies. pp. 404-425. *In* Trans. Forty-fourth N. Amer. Wild. Natr. Resour. Conf. Wildlife Management Institute. Washington, D.C.
14. Mooney, H. A., ed. 1977. Convergent evolution in Chile and California: Mediterranean climate ecosystems. US/IBP Synthesis Series 5. Dowden, Hutchinson and Ross, Inc. Stroudsburg, Pa.
15. Boudling, K. E. 1978. Ecodynamics: a new theory of societal evolution. Sage Publications. Beverly Hills, Calif.
16. Regier, H. A., and D. J. Rapport. 1978. Ecological paradigms, once again. Bull. Ecol. Soc. Amer. Spring Issue, March 1978. pp. 2-6.
17. Lindblom, C. E. 1959. The science of "muddling through." Public Administration Review 19:79-88.
18. Holling, C. S. 1977. The curious behavior of complex systems: lessons from ecology. pp. 114-129 *In* H. A. Linstone and W. H. C. Simmonds, ed. Futures research: New Directions. Addison-Wesley Publishing Co. Reading, Mass.
19. Holling, C. S., ed. 1978. Adaptive environmental assessment and management. Volume 3. International Series on Applied Systems Analysis. John Wiley and Sons. New York, N.Y.

20. Hilborn, R. 1979. Some failures and successes at applying systems analysis to ecological management problems. Miscellaneous Paper R-18, Institute of Resource Ecology, University of British Columbia. 32 pp.

21. Hammond, K. R., and L. Adelman. 1976. Science, values, and human judgment. Science. 194:389-396.

22. Odum, E. P., and J. L. Cooley. 1980. Ecosystem profile analysis and performance curves as tools for assessing environmental impact. pp. 94-102 *In* Biological Evaluation of Environmental Impacts: The Proceedings of a Symposium. Council on Environmental Quality and Office of Biological Services, Fish and Wildlife Service, USDI. FWS/OBS-80/26. 237 pp. U.S. Government Printing Office: 1980 0-326-334.

23. States, J. B., P. T. Haug, T. G. Shoemaker, L. W. Reed, and E. B. Reed. 1978. A systems approach to ecological baseline studies. FWS/OBS-78/21. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.

24. Department of Interior. 1980. Proposed Guidance for National Environmental Policy Act (NEPA) Implementing Procedures. Bureau of Land Management, Part II. Federal Register 45(55):17782-17830. March 19, 1980.

CLASSIFICATION SYSTEMS FOR HABITAT AND ECOSYSTEMS

Robert G. Bailey

During the 1930s, the federal land management agencies began to inventory and study a broad range of individual natural resources and plan for their development.[1] By the late 1950s, it was apparent that looking at individual resources by themselves was too limited. One thing that was lacking was a uniform and integrated classification system. At the same time, land managers became more acutely aware of the integrated nature of the landscape and its resources. It was also confirmed that of these resources, wildlife is an integral component.

Past wildlife studies and inventories have proceeded without the benefit of an integrated system. Biologists often had to depend on any available, sometimes inadequate, information or devise their own habitat[*] classification, usually a map featuring forest cover. Many investigators gathered disconnected bits of descriptive information on habitat without a classification framework to give them meaning. Without such a framework, it was very difficult and sometimes impossible to integrate wildlife information with other information for evaluating trade-offs or interactions within the wildlife and fish resource and between it and other natural resources. As of 1970, there was no national approach to integrating wildlife information. A new tool was needed to help biologists do their jobs better.

In the early 1970s, new federal legislation such as the Resources Planning Act, with regulations and executive orders, required greatly increased consideration of environmental consequences of natural resources management. This development generated concerted efforts by various federal agencies to develop a comprehensive classification of land. These efforts have encountered a number of difficulties. The greatest lies in formulating a common base for the many prospective users. Certain land attributes must be included for some users, but these attributes may be of marginal interest to other users. For example, according to Thomas, animal habitat is the arrangement of food, cover, and water required to meet the biological needs of one or more individuals of a species.[2] Habitat classification, based on an analysis of these needs, has long been a basic tool of wildlife and fisheries management. Because different species rarely have the same needs, the classification of a land area for one species must often be revised for another. The result is likely to be that the pattern of units will differ for each species considered.

This approach does not satisfy the needs for integrated information about the land and its wildlife resources. Interactions among species as well as between wildlife and other resource outputs for the same unit of land must be considered if environmental

---

The Author: Robert G. Bailey is geographer, Resources Evaluation Techniques Program, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80526. He holds a PhD degree in geography from the University of California, Los Angeles, and has authored several publications in the field of ecological land classification.

[*] Throughout this paper, the term "habitat" is used generally to denote both wildlife and fish. The term "wildlife information" denotes both population and habitat.

laws and multiple use mandates are to be complied with. It has therefore been recognized that an integrated classification system is needed.

In the United States work to develop such a system over the past decade has involved the ecosystem concept.[3] Ecological land classification refers to an integrated survey approach in which areas of land, as ecosystems, are classified according to their ecological unity. This paper presents an overview of some of the best-known classification systems and highlights future needs.

THE ECOSYSTEM CONCEPT

The ecosystem concept regards the earth as a series of interrelated systems in which all components are linked, so that a change in any one component may bring about some corresponding change in other components and in the operation of the whole.[4] An ecosystem approach to land evaluation stresses the interrelationship among components rather than treating each one as a separate characteristic of the landscape.

One of the more significant aspects of ecosystems in assessment and planning is that they constitute real units of the natural world and can be approximately identified on the ground. Thus, they form logical operating units for environmental planning and direction. Rowe defined an ecosystem as "...a topographic unit, a volume of land and air plus organics contents extended areally over a particular part of the earth's surface for a certain time."[5] As such, ecosystems are discrete geographic units of the landscape that include all natural phenomena and that can be identified and surrounded by boundaries.

The boundaries of ecosystems, however, are never closed or impermeable; they are open to transfer of energy and materials to or from other ecosystems. The open nature of ecosystem boundaries is important, for the exchange of material with its surroundings is an important aspect of the system's operation.

The term *ecosystem* is used quite generally without reference to spatial dimensions.[6] The largest ecosystem is formed by the planet Earth; examples of small ecosystems include a narrowly limited, homogeneous stand of vegetation or a small pond. In order to cover all ecosystems at all levels of planning and management, it is necessary to set up a defined hierarchy of ecological units of different sizes. Since ecosystems are spatial systems, they will be consistently inserted, or nested, into each other. Each level subsumes the environment of the system at the level below it. At each level, new processes emerge that were not present or not evident at the next lower level. As Odum[7] noted, results at any one level aid the study of the next higher level but never completely explain the phenomena occurring at that level, which itself must be studied to complete the picture.

The aim of ecological land classification is to provide a system that expresses the interactive character of the ecosystem's components, viz. soil, water, climate, flora, and fauna. Such classification also embodies the relationship between systems of different size in a spatial hierarchy. Instead of stressing an isolated component of the system, it focuses on a holistic concept of land which considers arrangements in space and time and processes that emerge from them.

Ecological classification systems are essential to any resource management effort. By identifying geographic areas as ecosystems with similar properties, these systems permit the design of cost-effective sampling programs and the aggregation of information. Because similar ecological units can be expected to respond in like manner to similar management practices or environmental stresses, classification systems increase our ability to generalize, to extrapolate research results, and to transfer management experience. There is not yet a generally accepted ecosystem classification system guiding federal and state agencies in wildlife habitat management.[8] The development of compatible systems for inventories of natural resources is critically needed in order to coordinate future management efforts.

CLASSIFICATION SYSTEMS

Ecosystem classifications in the United States have been developed based on a variety of criteria ranging from primarily biological[9,10] to primarily physical.[11] A relatively standard classification originally developed by Daubenmire,[12] in the western United States, is based primarily on vegetation. The units derived from this classification are called habitat types. This approach that now extends to at least half of the forested lands in the west[13] rests on the assumption that vegetation is the best integrated expression of the total ecosystem.

In other schemes, an attempt is made to classify ecosystems on the basis of biotic and abiotic criteria so as to identify land units where ecosystem components are integrated in a similar way. The concept of integrating more than one system to identify homogeneous units of land was expressed in ECOCLASS.[14] A potential vegetation classification and a land and aquatic system were linked to define ecological units. Combinations could be made from selected levels of the hierarchy in each respective system. Dashed lines in Figure 1 indicate possible integrations which could yield an integrated classification unit useful to management. Modified versions of ECOCLASS[15] have been developed for some areas in the western United States.

The concept was expanded to link classification to management needs in ECOSYM.[16] Several component classifications, each with its own hierarchy of levels, were developed on the basis of recognized land-management needs. In this procedure, different approaches to classifying the landscape or its resources are viewed as a series of overlays and are only integrated by the manager for a particular purpose. The integrity of each classification remains intact through many combinations and recombinations.

Another concept of integration is found in the land systems approach. Land systems inventory refers to an integrated approach to land survey in which areas of land, as ecosystems, are classified according to their ecological unity. The classification process involves the delineation, description, and evaluation of relatively homogeneous units of land at the local or regional scale. This approach assumes that all components may not be equally significant at different levels in the spatial hierarchy nor that it is possible to deal with all components simultaneously. It

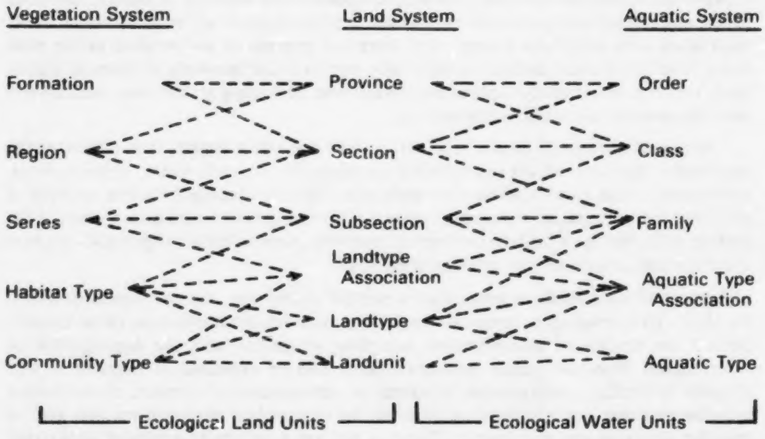


Figure 1. Basic systems of the ECOCLASS method, showing the hierarchical classification and possible combinations. (Adapted from Corliss[14])

depends rather on a hierarchy of components that reflects their level of control on the location, size, productivity, structure, and function of the system. Thus, components which exert the most control are at the highest level in the system (Table 1). The differentiating criteria at the upper levels with the greatest controls are broad and general in importance. Those at lower levels are narrow and more specific in importance. Figure 2 shows the major ecosystems of the United States delineated in this manner.

This approach emerged in the late 1960s when Forest Service soil scientists sought to rapidly differentiate and classify ecologically significant segments of the land surface on a small scale. Land systems inventory, as proposed by Wertz and Arnold,[20] has since been expanded by Bailey[21,22] from concepts advanced by

Table 1. Levels of generalization in a hierarchy of ecosystems (from Bailey[21]).[a]

	Name	Defined as including:
1.	Domain	Subcontinental areas of broad climatic similarity identified by zonal heat and water balance criteria.
2.	Division	A part of a domain identified by macroclimatic criteria generally at the level of Köppen's types.[17]
3.	Province	A part of a division identified by bioclimatic and soil criteria at the level of soil orders and classes of vegetation formations.
4.	Section	A part of a province identified by a single climatic vegetation climax at the level of Küchler's potential vegetation types.[18]
5.	District	A part of a section identified by Hammond's land-surface form types.[19]
6.	Landtype association	A part of a district determined by isolating areas whose form expresses a climatic-geomorphic process.
7.	Landtype	A part of a landtype association having a fairly uniform combination of soils (e.g., soil series) and chronosequence of vegetation at the level of Daubenmire's habitat type.[12]
8.	Landtype phase	A part of a landtype based on variations of soil and landform properties such as soil drainage and slope that affect the productivity of the habitat type.
9.	Site	A part of landtype phase that is homogeneous in respect to all components, their appearance, potential to produce biomass, limitations to use and response to management.

[a] As these levels of generalization are hierarchically nested, a lower order of generalization (e.g., section) is a subset of a higher (e.g., province), and therefore, contains its characteristics as well. Regional ecosystems or ecoregions are designated at levels 1-5.

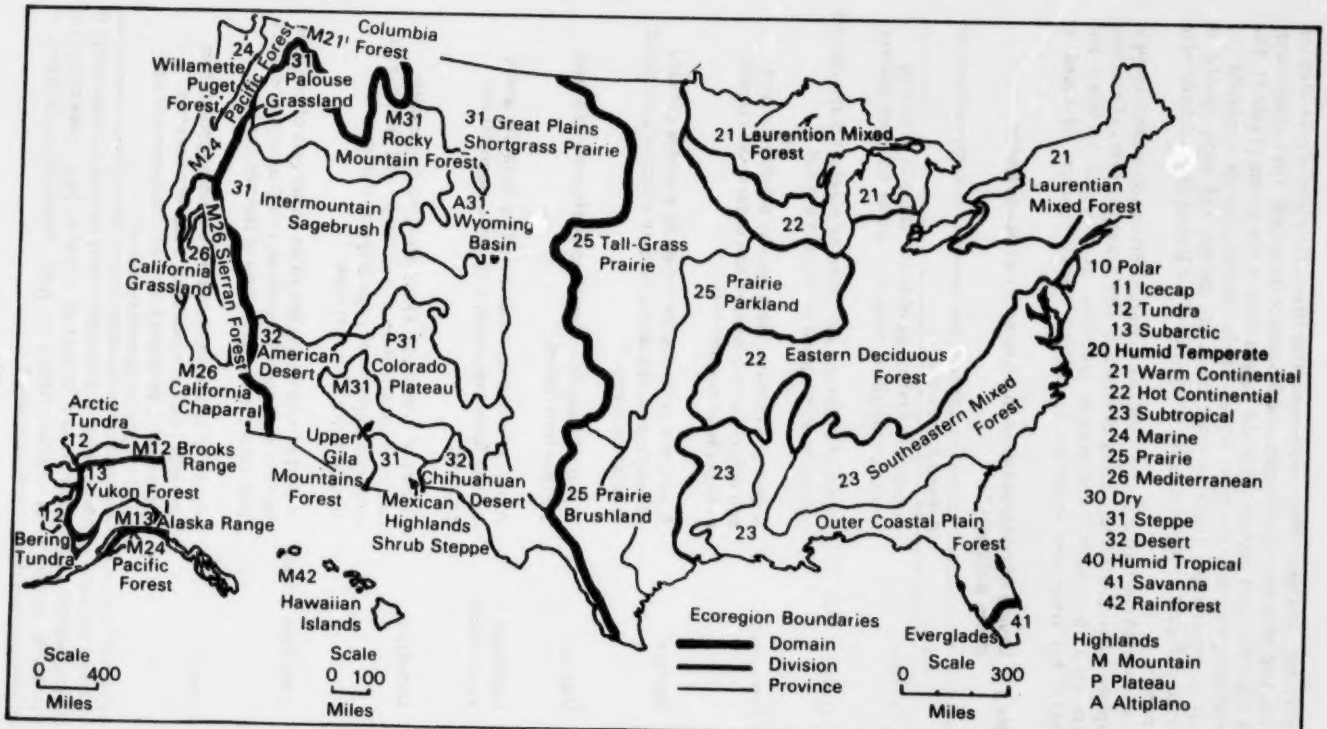


Figure 2. Third-order ecosystem regionalization of the United States (from Bailey[21]).

Crowley.[23] This kind of ecological partitioning follows existing national and regional schemes, whereas the basic concepts and principles of the approach were based on international experiences.

The principal agencies involved with natural resource inventories have agreed to coordinate work on classification systems. Hirsch et al. have outlined the coordination efforts of the federal agencies under an *Interagency Agreement Related to Classification and Inventories of Natural Resources.*[8]

In 1976, the Forest Service began planning for a new classification system for the 1990 national assessment required by the Resources Planning Act. Because of the need for and interest in an interagency land classification system, several other agencies, especially the Bureau of Land Management, Fish and Wildlife Service, Geological Survey, and Soil Conservation Service, became involved in the development of the system. These agencies are developing a single National Site (Land) Classification System. The system, like ECOCLASS, is a component system. It was prepared,[24] reviewed, and tested in the field. It is based upon four relatively independent components—vegetation, soil, landform, and water—organized into a hierarchial classification structure (Table 2). A recent interagency review endorsed the concept embodied in the system, suggested major revision in the landform and water components, and noted the need for further work in relating the system to mapping procedures, sampling techniques, and component integration. Also identified was the need for further refinement of the vegetation component to more succinctly define the linkages between climax vegetation and existing vegetation.

Currently, the Forest Service's Resources Evaluation Techniques Program is working on completion of the classification system.[25] Included in this work is the development of a process of combining (integrating) the components into a hierarchial ecosystem classification scheme suitable for national assessments/appraisals, land management planning, and program planning.

The Bureau of Land Management aggregates wildlife data according to its Integrated Habitat Inventory Classification System.[26] This classification provides a six-level hierarchial system for organizing species occurrence data from the smallest geographic units (special features and plant communities) to the largest units (physiographic regions). At the higher classification levels, data can be crossed into other classifications, including Küchler's[18] associations and Bailey's[21] ecoregions. Since the lowest level at which inventory data are collected is the present and potential plant community, these data can be used in component classification including the National Site Classification System. The Bureau of Land Management is developing a classification system for aquatic wildlife habitats, in which consideration is given to the Fish and Wildlife Service's wetland/aquatic classification.[29]

The Soil Conservation Service is basing its Resource Conservation Act assessment on a classification organized around relationships which are significant to natural resource use on a state and farm production region basis. This approach groups the organizational geographic units related to land use, topography, climate, water, and soil into Land Resource Regions and Major Land Resource Areas.[30] The collected data are statistically reliable at state level aggregation.

The Fish and Wildlife Service has developed a classification system for wetlands and associated aquatic habitats which is being used to conduct the National Wetlands Inventory.[29] This system is expected to replace that developed by Martin et al.,[31] which has been widely utilized for wetlands management since its publication. The Fish and Wildlife Service has also been developing improved approaches to wildlife habitat classification for habitat other than wetlands and is working closely with the other concerned agencies in developing compatible systems.

The Geological Survey's Land Use and Land Cover Mapping Program[32] provides broad-based information. Although it is not intended for wildlife habitat classification, the USGS program can assist in interpreting wildlife habitat information.

Table 2. Basic components and categories of the National Site (Land) Classification System for Renewable Resources.[a]

Vegetation Components[b]	Soil Components[c]	Landform Components[d]	Aquatic (water) Components[d]
Formation Class	Order		
Formation Subclass	Suborder		
Formation Group	Great Group		
Formation	Subgroup		
Subformation	Family		
Series	Series		
Association			
•			
•			
•			
Others as needed	Others as needed		

[a] It must not be construed that equivalency exists between apparent similar levels of the component systems. For example, a Vegetation Formation—Soil Subgroup—should not be equated on a 1:1 basis. Integrated (elemental) landscape units are formed by combining component classes of the hierarchies to define ecological units which should be expected to respond similarly to management treatments and practices at different levels of generalization.

[b] Adapted from UNESCO.[27] The Series and Association classes are extensions of the UNESCO System and are subsequently defined in Merkel et al.[25]

[c] The Soil Taxonomy[28] used by the U.S. National Cooperative Soil Survey.

[d] Under development; the landform component considering both genetic and morphometric approaches. The water (aquatic) component considering water as a medium to support life on and in the water.

Although each of these federal agencies has special information needs and separate classification systems to meet those needs, all are currently working together to attempt to develop common or compatible systems. This interagency cooperation is designed to produce a truly multipurpose classification system for multiagency use in inventory programs.

For comprehensive discussion of current problems associated with development of classification systems, see the special issue on classification in the Journal of Forestry (October 1978), and the *Proceedings, National Symposium on Classification, Inventory, and Analysis of Fish and Wildlife Habitat.*[33]

FUTURE NEEDS

The development of an ecological land classification system is not yet complete. The following three major tasks remain:

1. The continued controversy over the type or types of land classification to be used in resource inventories, assessments, and planning has not been resolved. Despite interagency cooperative agreements, few objective evaluations of the process appear to be underway. There is a need to evaluate the effectiveness and efficiency of various classification approaches. This will require an analysis of both the role of land classification and the kind of information it is expected to provide. With such analysis, the ability of various systems to deliver appropriate information can be evaluated.
2. Ecological and classification is meant to be an integrated approach to land survey. As such, the physical and biotic characteristics of land and their interactions must be studied and integrated. Wildlife is perhaps one of the most difficult components to fit into an ecological land survey. Taylor[34] has summarized the reasons as follows:
    a. Animals are less conspicuous than components such as vegetation and landforms. Although the largest species may be checked by aerial census, very few species are suitable for remote sensing;
    b. Whereas landforms or vegetation are sedentary, the mobility and behavior patterns of animals make them difficult to study within a short time; and
    c. Habitat units perceived by an animal may or may not coincide with identified land ecosystems, or with all parts of any particular land ecosystems. For example, a pika may recognize only one talus slope as important, in contrast, elk may recognize various areas throughout the mountain range as important at different times of the year.

    Despite these difficulties, our approach should incorporate the wildlife component if we are to conduct a fully integrated land survey. To accomplish this, we need a clear definition of the term "wildlife" and a rationale for incorporating wildlife into ecological land classification schemes (i.e., of what value would wildlife information be?).
3. Existing classification systems usually emphasize the soil/vegetation complex, mainly because land classifiers do not understand aquatic habitats. In most landscapes, water bodies are so intricately associated that integrated survey is essential. This need is emphasized by the fact that aquatic ecosystems are controlled by the lands around them. This is a key point because a holistic approach should be capable of recognizing integrated terrestrial/aquatic systems. Attempts to relate to land through separate systems have, in part, had limited success because they were regarded as independent systems.

We need a nationally accepted method that will compatibly incorporate water with the surrounding terrain. Such a method being developed is part of the work on the water component of the National Site (Land) Classification System (T. Terrell, Fish and Wildlife Service, personal communication). Platts[35] has also reported on studies that integrate aquatic ecosystems with terrestrial ecosystems through the land systems inventory concept. The Environmental Protection Agency is working on a rationale for unified and practical land/water classification.[36] Although this effort is promising, much additional work needs to be done to implement such an approach.

Clearly, to accomplish these tasks, coordination is necessary. Besides interagency agreements to coordinate programs for classification and inventory of natural resources, there is a need to assure that coordination takes place within a broader context to deal with the questions of philosophy, application, and definitions. A vehicle for such coordination could be modeled after the very successful Canada Committee on Ecological Land Classification.[37]

SUMMING UP

Systems for classifying and evaluating land as ecosystems have evolved in different agencies of the federal government over the past decade. Such systems involve the delineation, description, and analysis of relatively homogeneous units of land at the local or regional scale. The concept of the ecosystems has been widely accepted as a basis for organizing our knowledge of fish and wildlife resources and for considering their interaction with other resources. Although some commonality of ideas exists at present, there is no uniform approach to ecological land classification. Cooperative efforts are underway to develop common or compatible systems. As part of these efforts, the problem of integrating wildlife data into the ecological land classification process and of integrating land/water ecosystem concepts must be resolved.

REFERENCES

1. Bailey, R. G., R. D. Pfister, and J. A. Henderson. 1978. Nature of land and resource classification—a review. J. Forestry. 76:650-655.
2. Thomas, J. W., ed. 1979. Wildlife habitats in managed forest—the Blue Mountains of Oregon and Washington. USDA Forest Service. Agric. Handbk. 553. Washington, D.C. 512 pp.
3. Coulombe, H. N. 1978. Toward an integrated ecological assessment of wildlife habitat. pp. 5-23 *In* Proc. National Workshop on Integrated Inventories of Renewable Natural Resources. Tucson, Ariz. Jan. 8-12, 1978. General Tech. Report RM-55. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.
4. Bailey, R. G. 1980. Integrated approaches to classifying land as ecosystems. In press. *In* Proc. IUFRO/ISSS Workshop on Land Evaluation for Forestry, Wageningen, The Netherlands. Nov. 10-14, 1980.
5. Rowe, J. S. 1961. The level-of-integration concept and ecology. Ecology 42:420-427.
6. Webster, J. R. 1979. Hierarchical organization of ecosystems. *In Theoretical Systems Ecology*. E. Halfon, ed. Academic Press. New York, N.Y.
7. Odum, E. P. 1977. The emergence of ecology as a new integrative discipline. Science 195:1289-1293.
8. Hirsch, A., W. B. Krohn, D. L. Schweitzer, and C. H. Thomas. 1979. Trends and needs in federal inventories of wildland habitat. pp. 340-359. *In* Trans. N. Amer. Wildl. and Natr. Resour. Conf. March 24-28, 1979, Toronto, Ontario, Canada. Wildlife Management Institute, Washington, D.C.
9. Garrison, G. A., J. J. Bjugstad, D. A. Duncan, M. E. Lewis, and D. R. Smith. 1977. Vegetation and environmental features of forest and range ecosystems. Agric. Handbk. 475. USDA Forest Service. Washington, D.C. 68 pp.
10. Brown, D. E., C. H. Lowe, and C. P. Pase. 1980. A digitized systematic classification for ecosystems with an illustrated summary of the natural vegetation of North America. General Tech. Report RM-73, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo. 93 pp.
11. Godfrey, A. E. 1977. A physiographic approach to land use planning. Environmental Geology. 2:43-50.
12. Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. Harper and Rowe. New York, N.Y. 300 pp.
13. Pfister, R. D. 1977. Ecological classification of forest land in Idaho and Montana. pp. 329-358. *In* Proc. Ecological Classification of Forest Land in Canada and Northwestern USA. Univ. British Columbia, Vancouver, Canada.
14. Cortiss, J. C. 1974. ECOCLASS—A method for classifying ecosystems. pp. 264-271. *In* Foresters in Land-Use Planning. Proc. 1973. Nat. Convention Soc. Amer. For., Washington, D.C.

15. Buttery, R. F. 1978. Modified ECOCLASS—A Forest Service method for classifying ecosystems. pp. 157-168. *In* Proc. Integrated Inventories of Renewable Natural Resources. Tucson, Ariz. Jan. 8-12, 1978. General Tech. Report RM-55, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

16. Henderson, J. A., L. S. Davis, and E. M. Ryberg. 1978. ECOSYM: A classification and information system for wildland resource management. Utah State University. Logan, Utah. 30 pp.

17. Trewartha, G. T. 1943. *An Introduction to Weather and Climate.* Second edition McGraw-Hill. New York, N.Y. 545 pp.

18. Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States (map and manual). Amer. Geog. Soc. Spec. Pub. 36. 116 pp.

19. Hammond, E. H. 1964. Analysis of properties of landform geography: An application to broad-scale landform mapping. Annals Assoc. Amer. Geogr. 54:11-23.

20. Wertz, W. A., and J. F. Arnold. 1972. Land systems inventory. USDA Forest Service, Intermountain Region. Ogden, Utah. 12 pp.

21. Bailey, R. G. 1976. Ecoregions of the United States (map). USDA Forest Service, Intermountain Region. Ogden, Utah.

22. Bailey, R. G. 1978. Description of the ecoregions of the United States. USDA Forest Service, Intermountain Region. Ogden, Utah. 77 pp.

23. Crowley, J. M. 1967. Biogeography. Can. Geog. 11:312-326.

24. Driscoll, R. S., J. W. Russell, and M. C. Meier. 1978. Recommended national land classification system for renewable resource assessments. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo. 44 pp. mimeo.

25. Merkel, D. L., R. S. Driscoll, D. L. Gallup, J. S. Hagihara, D. O. Meker, D. W. Snyder, and T. T. Terrell. In prep. National site (land) classification system—status and plans. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

26. U.S. Department of Interior, Bureau of Land Management. 1978. Integrated habitat inventory and classification system, BLM Manual Section 6602. Washington, D.C. 37 pp.

27. UNESCO. 1973. International classification and mapping of vegetation. Series 6, Ecology and Conservation, United Nations Education, Scientific and Cultural Organization. Paris, France. 92 pp.

28. U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agric. Handbk. 436. Washington, D.C. 754 pp.

29. Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. USDI. FWS/OBS-79/31. Fish and Wildlife Service, USDI. Washington, D.C. 103 pp.

30. Austin, M. E. 1965. Land resource regions and major land resource areas of the United States (exclusive of Alaska and Hawaii). USDA Soil Conservation Service Agric. Handbk. 296. Washington, D.C. 82 pp.

31. Martin, A. C., N. Hotchkiss, F. M. Uhler, and W. S. Bourn. 1953. Classification of wetlands of the United States. Special Scientific Report (Wildlife) 120. Fish and Wildlife Service, USDI. Washington, D.C. 14 pp.

32. Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Professional Paper 964. Geological Survey, USDI. Reston, Va. 28 pp.

33. U.S. Fish and Wildlife Service. 1978. Proc. Classification, Inventory, and Analysis of Fish and Wildlife Habitat. Jan. 23-27, 1977. Phoenix, Ariz. FWS/OBS-78/76. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 604 pp.

34. Taylor, D. 1978. Wildlife in ecological land classification studies. pp. 3-5. *In* Newsletter No. 4 Canada Committee on Ecological (Bio-physical) Land Classification. Lands Directorate, Environment Canada, Ottawa, Ontario, Canada.
35. Platts, W. S. 1980. A plea for fishery habitat classification. Fisheries 5:2-6.
36. Warren, C. E. 1979. Toward classification and rationale for watershed management and stream protection. Corvallis Environmental Research Lab. U.S. Environmental Protection Agency. Corvallis, Ore. EPA-600/3-79-059. 142 pp.
37. Wiken, E. B. and G. Ironside. 1977. The development of ecological (biophysical) land classification in Canada. Landscape Planning 4:273-275.

SPECIES/HABITAT RELATIONSHIPS - A KEY TO CONSIDERING WILDLIFE IN PLANNING AND LAND MANAGEMENT DECISIONS

Jack Ward Thomas

THE 1970s — A TIME OF REVOLUTION

The period 1969-1980 brought a revolutionary change in how Americans view wildlife and its management. The change, a revolution in perception, was simply the recognition that *all* wildlife is important in and of itself and as part of a larger functioning whole — an ecosystem. This perceptual revolution, in concept, is now fixed firmly in law, but its impacts are gradually working their way into full-scale application by governmental agencies at both state and federal levels.

For many years before 1969, wildlife was defined in practical terms by governmental bodies as those species hunted for sport, trapped for furs, controlled to accomplish human objectives, or of particular aesthetic value. Governmental management of these species was based on funding obtained from or supported largely by clearly identified constituencies.

Universities evolved specialized programs in wildlife biology and management to produce the knowledge and trained professionals to meet these needs. Many such programs were oriented toward training in zoology which, in the opinion of some, emphasized the animal and populations while paying less attention to habitat.

As a result, most wildlife research was focused on a few species, and it was directed to their taxonomy, population level and dynamics, life history, behavior, distribution, and food habits. Comparatively little effort was spent on defining habitat requirements of even these select species. And little attention was given to the study, welfare, and management of other species.

For many decades preceding the revolution, scientists expanded the science of ecology. They taught principles of ecological management to generations of wildlife managers and researchers. Those students went to work in mission-oriented organizations that served well-defined constituencies such as hunters and fishermen, and the wood-products and livestock industries. Simultaneously, ideas about a holistic management philosophy were reaching thousands of other people. New interest groups formed around wildlife for reasons other than or in addition to sport hunting, trapping, nuisance wildlife control, etc. Suddenly, as if a dam had broken, flood of state and federal legislation occurred mandating that these revolutionary perceptions be put into action through governmental agencies dealing with wildlife management. For many practicing wildlife professionals this has forced a wrenching adjustment to new realities.

The seminal legislation that stirred this revolution in concept was the National Environmental Policy Act of 1969 (NEPA).[1] NEPA required that the environmental consequences, including impacts on wildlife, of any activity involving federal funds

---

The Author: Jack Ward Thomas, B.S., M.S. (Wildlife Management), Ph.D. (Forestry), worked 10 years for the Texas Parks and Wildlife Department and 14 years for the USDA Forest Service where he is currently a Chief Research Biologist. Thomas has authored some 150 publications on wildlife and wildlife habitats.

be described before action is taken on the project. This necessitated a broadening not only of the definition of wildlife but also of the *understanding and description of wildlife in relation to habitat*. Other legislation that mandated better and broader consideration of wildlife emerged in 1969 and the 1970s, for example, the National Forest Management Act of 1976,[2] the Endangered Species Conservation Act of 1969,[3] the Endangered Species Act of 1973,[4] and the Forest and Rangeland Renewable Resources Planning Act of 1974.[5] Still, the National Environmental Policy Act of 1969[1] set the stage in terms of what had to be described and considered in response to the new legislative mandates. That revolutionary concept now embodied in law and associated regulations and tested in the courts makes it essential that biologists be able to relate all species to habitat conditions and to predict species response to habitat alterations. The task is enormous and perhaps one of the most challenging ever to face professionals in wildlife biology and other areas of applied ecology.

MANAGEMENT NEEDS AND THE DATA BASE

Sufficient data to accomplish this task are available for relatively few of the vertebrate species in the United States. Research data on the relationships of species to habitat continue to emerge, mostly in bits and pieces, and seemingly at an increasing rate. But it will be many decades before a data base totally derived from well-designed site-specific research is available in a form that is readily adaptable to large scale planning. This problem is further aggravated by the fact that existing information on species/habitat relationships is scattered throughout the literature and is not consistent as to research approach, analysis, or reporting. Existing and emerging research data on species/habitat relationships can be generally categorized as fragments of information of varying quality from many locations that contribute, like pieces of a jig-saw puzzle, to some usable understanding of selected species/habitat relationships.

In short, it has become increasingly obvious that biologists should try to put existing knowledge and theory into a framework that can be utilized in land-use planning and in helping to meet legal mandates. That process requires the innovative use of basic ecological principles in formulating systems for analyzing existing data. When statistically sound results from replicated scientific studies are not available, the opinions of qualified experts will have to continue to serve until the gaps in knowledge, identified through the planning and evaluation process, are filled.

WILDLIFE MANAGEMENT STRATEGIES

The scientifically based art of wildlife population and habitat management in land-use planning usually takes one of three forms: (1) featured species management,[6] (2) species richness management,[7] or (3) some combination of the two (Figure 1). In featured species management, the objective is production of selected species in desired numbers in specified places and times. With species richness management, the aim is to insure that a broad spectrum of species is maintained within a geographic area of concern (Figure 2).

Featured species management has been most commonly pursued by state and federal agencies. The information needed to carry out the habitat manipulation aspects was determined by studying the habitat requirements of the particular featured species. As a result, much of the research on species/habitat relationships has focused on comparatively few species. This information was usually gathered by studying how a species was related to its habitat in a particular place.

Species richness management came more into vogue in state and federal land management agencies with the advent of increasing environmental awareness and resultant state and federal legislation. The vast number of wildlife species present or potentially present in any area makes it impractical to study individually the relationship of each species to its habitat. Probable advantages are to be gained in

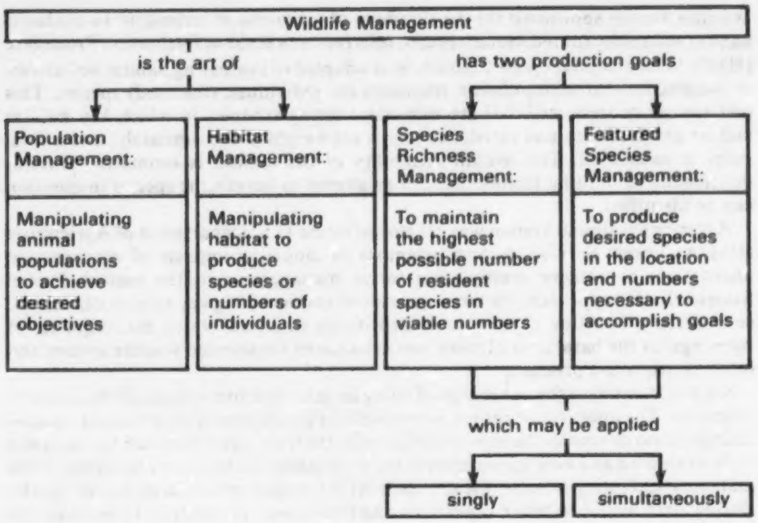
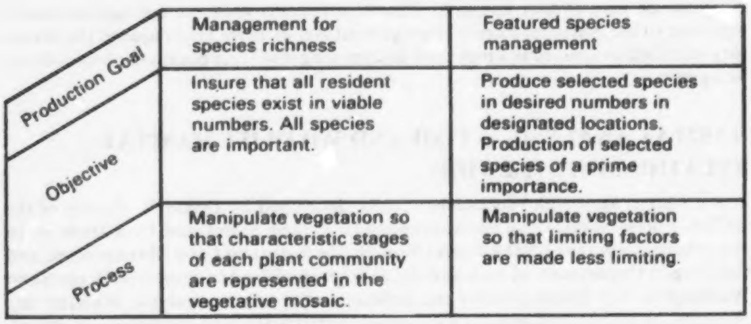

Wildlife Management
is the art of
has two production goals
Population Management:
Manipulating animal populations to achieve desired objectives
Habitat Management:
Manipulating habitat to produce species or numbers of individuals
Species Richness Management:
To maintain the highest possible number of resident species in viable numbers
Featured Species Management:
To produce desired species in the location and numbers necessary to accomplish goals
which may be applied
singly
simultaneously

Figure 1. The kind and goals of wildlife management.[8]



Production Goal	Management for species richness	Featured species management
Objective	Insure that all resident species exist in viable numbers. All species are important.	Produce selected species in desired numbers in designated locations. Production of selected species of a prime importance.
Process	Manipulate vegetation so that characteristic stages of each plant community are represented in the vegetative mosaic.	Manipulate vegetation so that limiting factors are made less limiting.

Figure 2. The goals, objectives, and process of major kinds of management.[8]

cost and time from describing habitats in terms of categories such as plant communities and successional stages or structural conditions and by subsequently relating the species present to those habitat categories.

HABITAT ANALYSIS — HABITAT EVALUATION PROCEDURES (HEP)

Two predominant approaches evolved in the 70s to answer the demands of the law and the need for information on species/habitat relationships. The U.S. Fish and

Wildlife Service sponsored the development of a process or technique to evaluate habitat suitability for individual species, referred to as Habitat Evaluation Procedure (HEP).[9] The procedure is particularly well-adapted to evaluating habitat suitability or judging habitat manipulation responses for individual, (featured) species. This and similar procedures[10,11,12] are numerical rating schemes in which key habitat factors are described and rated, the scores are weighted appropriately, and a final value is calculated. The overall suitability of the habitat is estimated. Habitat deficiencies or limiting factors that can be altered to benefit the species in question can be identified.

A somewhat similar system was developed by the U.S. Department of Agriculture (USDA) Forest Service research scientists in modeling impacts of management alternatives to achieve multiple-use forest management in the eastern United States.[13] In this approach, the consequences of manipulating key habitat characters, such as the proportion of the area in identifiable structural states, the frequency of openings, or the basal area of trees, were evaluated for selected wildlife species and other multiple-use products.

Such systems have the advantage of being largely objective and usable by different observers. The question, of course, is how well the developers of the particular species rating system or species/habitat model identify the truly significant habitat variables to be evaluated and how appropriately these variables are valued or weighted in the mathematical rating scheme. Ideally, each HEP for each species in each ecologically distinct area would be tested repeatedly and fine-tuned accordingly. In practice this has seldom been the case because of the large costs involved.

HEP can be utilized in species richness evaluation management, preparation of environmental impact statements, and generalized wildlife habitat evaluation. This is done by preparing a HEP for a species that serves as an indicator of certain habitat conditions or, conversely, stands as a surrogate for a group of species that requires the same or very similar habitats. This is in keeping with the regulations issued pursuant to the National Forest Management Act of 1976[2] that requires the inventory of indicator species as a means of determining if wildlife planning objectives are being met.

HABITAT ANALYSIS — FISH AND WILDLIFE HABITAT RELATIONSHIPS (F&WHR)

A different approach was independently developed by David R. Patton of the USDA Forest Service[14] in the southwestern United States and by a team of 16 contributors from the USDA Forest Service, the Bureau of Land Management, and the Oregon Department of Fish and Wildlife for the Blue Mountains of Oregon and Washington.[15,16] These systems use habitat as the key to analysis. Habitats are classified or categorized and the wildlife associated with these conditions identified. Although the earlier work of Hudson G. Reynolds and R. R. Johnson[17] was confined to one small study area, it was much the same in approach. They[14,16] presented principles, concepts, and techniques that were found to be adaptable to other areas. These efforts provided the direction and framework for the development of species/habitat information systems and models that are underway or planned for most of the USDA Forest Service's 10 regions.[18] This approach to systematic consideration of species/habitat information has become known in the Forest Service as the Fish and Wildlife Habitat Relationships (F&WHR) system (although considerations of fish life are just now being developed[18]).

Salwasser et al.[18] stated the following:

> Fish and Wildlife Habitat Relationships (F&WHR) is a relatively new term —it is not a new philosophy or approach to resource management. It is simply the comprehensive organization of the vast array of existing infor-

> mation in a format that is useful in managing animals through managing their corresponding habitats. The philosophical basis for F&WHR dates back to Joseph Grinnel and Aldo Leopold. Intertwined is the current state-of-the-art of ecosystem approaches to natural resource management; in this case, an attempt to view wildlife habitat from the animal community as well as the single species perspective. The philosophy has been incorporated in the. . .environmental legislation of the 1970s that was mentioned earlier.

The F&WHR system has already been adapted for use in other areas of the west.[19,20,21] The system, originally applied to forest lands, is being adapted for rangelands of the great basin in southeastern Oregon in order to demonstrate applicability to rangeland conditions. Six of 14 planned "chapters" of this effort have been completed.[22,23,24,25,26,27]

The F&WHR system divides habitat considerations for terrestrial wildlife into three general parts: (1) the habitat (described by plant community and structural condition) association of each species for feeding, reproduction, and resting; (2) the value of special habitat elements (such as snags, edges, dead and down woody material, riparian zones, cliffs, caves, and talus) to associated species; and (3) development of more elaborate habitat capability models for selected or featured species.[14,16,19]

The information on species relationships to habitat is readily put into a form suitable for computer manipulation. It can then be used in long-range planning or in analyzing impact across the species spectrum of management alternatives that involve manipulation of vegetation. There have been several successful computer programs developed to handle various kinds and varieties of F&WHR data bases. Successful computer application has included both mini-computers and standard computers. By far the best known of these systems for storage and recall of data has been David R. Patton's RUN WILD system,[14] and its subsequent modification, the Procedure for Pennsylvania.[28]

HABITAT MANAGEMENT AND INDICATOR SPECIES

Thomas et al.[29] grouped species according to "life forms" that showed affinity to similar habitat. This concept was expanded from that proposed by Antti Haapanen for birds in the Finnish forest.[30] Most systematic groupings of species have been morphological in nature. Such groupings are flexible. Analysis can create as many categories as make biological sense in terms of habitat use in a localized area. Some knowledgeable works (Hal Salwasser, USDA Forest Service, personal communication) believe that ecological guilds will prove to be superior to life forms for the purposes described above. The important thing is that it probably will be necessary to group species in some manner that accounts for their response to habitat features.

These groupings were developed in anticipation of the regulations issued pursuant to the National Forest Management Act of 1976,[2] which specified the monitoring of indicator species in National Forest System management. Theoretically, indicator species represent or reflect the welfare of a larger group of species. The regulations call for a description of just what changes are implied for the status of the chosen indicator species. Once appropriate life forms are created for local situations, the welfare of a group of species that occurs within a plant community and successional stages can be represented by the status of an indicator species chosen from within that group. Some have tried to expand the use of the life form concept beyond the specific area for which the information was developed; it has worked poorly in such cases.

The appropriateness of using indicator species to reflect changes in habitat suitability or condition is a subject of continuing debate. Sampling of several indicator species status over vast areas of National Forests will be costly in time and money. Sampling must be intensive enough to focus upon statistical differences in populations between areas within sampling periods and between sampling periods within areas. The population or occurrence changes must then be carefully interpreted to assure that they reflect changes in habitat conditions rather than normal fluctuations in population levels or distribution. The description of just what an indicator species "indicates" must be accepted for the short term but somehow tested over the long term. It is feared that such an approach will be expensive to carry out, perhaps prohibitively so.

MONITORING HABITAT CONDITIONS

It seems much easier to inventory habitats, as categorized by plant communities and successional stage or other acceptable descriptors, and to relate those inventories to species. Such information might be obtained by making relatively minor changes in the routine information collected in standard forest survey efforts. These approaches are already being tested by USDA Forest Service forest inventory personnel in the Pacific Northwest and in the South.

The data so collected can be manipulated in or used in conjunction with existing linear programming models for considering alternatives for manipulation or allocations of timber and range resources. The USDA Forest Service's Timber RAM (Resource Allocation Model) is an example of such a linear programming model.[30,31]

MONITORING OF INDICATOR SPECIES

The regulations issued pursuant to the National Forest Management Act of 1976[2] clearly require the use of the indicator species approach in monitoring wildlife activities for National Forests. It is also likely that habitat inventory and analysis based on species/habitat relationships will be an additional means through which the welfare of the entire spectrum of vertebrate wildlife species is considered in Forest Service planning. Indicator species will probably be chosen primarily, as directed by the National Forest Management Act of 1976[2] regulations, from those endangered. The status of indicator species will probably reveal little beyond their own numbers. Therefore, when they are chosen as indicators, they are probably the same as those "featured"[8] or "selected"[18,19] species already provided for in the F&WHR process.

LAND-USE PLANNING

Land-use plans and environmental impact statements using the F&WHR approach have been praised by experienced reviewers as more comprehensive, better formulated, and more responsive to the intent of the law than those developed before this planning tool. The system has weaknesses, however. The information in the data base ranges from the thorough, well-documented, and site-specific to the speculation of knowledgeable biologists. Although many managers who deal continually with decision making under conditions of uncertainty view this as quite normal, some scientists are appalled by this state of affairs.

Land-use planning is presently based on interpretation and extrapolation of existing theory and data. Such an approach obviously involves an inherent danger of human error. The entire F&WHR system has been called a working hypothesis.[16] Research is already underway to test critical hypotheses and to improve the data base by providing additional or site specific data.

Most importantly, a system or framework for analysis exists that is acceptable to most of the concerned publics and state and federal agencies. Any such system must meet the bio-political test of acceptability if it is to be used successfully in land-use planning and preparation of environmental impact statements. This does not imply that arguments about resource allocations or management prescriptions are resolved by the existence of an acceptable system for data organization and analysis.

The development of a generally acceptable system, however, has provided a gaming board on which defined pieces may be manipulated to resolve problems involving economics, politics, law, ecology, aesthetics, and philosophy. Until the advent of such procedures as HEP and F&WHR in the 1970s, those interested in wildlife seemingly could not participate as effectively as other interest groups in land-use planning. With the development of such procedures, it has been easier for land-use planners to consider wildlife values.

HEP OR F&WHR — WHICH IS BEST?

Which of these two general approaches to species/habitat relationships analysis is best depends on the type of analysis required and the objectives of management. Close examination of the two approaches shows that rather than being radically different, they are really two ways to achieve the same goal—improved ability to predict wildlife response to potential alterations in habitat.

HEP type approaches begin with the analysis of habitat for a single species. These species may be the featured or indicator species described earlier. Species can be selected, however, that might serve in land-use planning or the analysis of alternative management actions as the indicator of the welfare of other species.

The F&WHR system starts with a data base that describes the general habitat requirements of all resident species; then, in one case,[28] combines those into groups based on similar habitat responses. This makes it possible to select an indicator species for the group more rationally. Once an indicator species is selected, it is necessary to develop a special and much more detailed write-up describing how the habitat of this species can be measured in land-use planning and subsequent management.

Existing examples of this type of treatment for a featured or selected species include Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) and Rocky Mountain elk (*Cervus elaphus nelsoni*) in the Blue Mountains of Oregon and Washington[32] and native trout (*Salmo* sp.) in the Great Basin of southeastern Oregon.[22] If the status of the featured species indicates management success, it is then necessary to census the species periodically.

HEP could be used to provide the habitat analysis mechanism when it is deemed necessary to fully describe habitat relationships for a featured species. In fact, for species featured under a F&WHR system, a special document must be prepared describing habitat requirements for the species and a process for their evaluation by procedures that have been very similar, conceptually if not yet procedurally, to the habitat suitability indices produced by the HEP procedure.

F&WHR and HEP were originally developed to serve different needs. Experience has shown that managers and analysts end up needing both systems. Thus, F&WHR and HEP, used in conjunction, play different but synergistic roles.

Although some managers and practitioners have praised HEP and F&WHR, others, primarily researchers, have validly criticized these operational systems because available knowledge and ecological theory must be extrapolated and recombined in untested ways to produce them. However, agencies are making strong attempts to meet the requirements of the law, and HEP and F&WHR programs have directed the attention of the wildlife research community to some of the major problems that must be solved. Likewise, information required to improve the data base and the theoretical foundation of these systems has been identified.

MANAGEMENT DECISIONS MADE IN UNCERTAINTY

The dilemma has been described in this way:

> The knowledge necessary to make a perfect analysis of the impacts of potential courses of . . . management action on wildlife habitat does not exist. It probably never will. But more knowledge is available than has

> yet been brought to bear on the subject. To be useful, that knowledge must be organized so it makes sense . . .
>
> Perhaps the greatest challenge that faces professionals engaged in . . . research and management is the organization of knowledge and insights into forms that can be readily applied. To say we don't know enough is to take refuge behind a half-truth and ignore the fact that decisions will be made regardless of the amount of information available . . . it is far better to examine available knowledge, combine it with expert opinion on how the ecological system operates, and make predictions about the consequences of alternative management actions.[33]

THE 1970s — JUST THE BEGINNING

It seems likely that HEP and F&WHR will continue their parallel evolution; eventually, they may evolve or be melded into a single system. They almost certainly will become more quantitative and more reliable as better data become available.[18] There have also been somewhat parallel efforts to develop a national data base and a national application of species/habitat relationship data. These are described in other chapters.[34,35]

Each successful effort should produce a more reliable and sophisticated product. The initial efforts should be quickly outdated and outmoded. The important thing is that the first steps have been taken.

In the 1970s, the way we view wildlife in planning and management changed radically. The National Environmental Policy Act of 1969 was the beginning. And wildlife biologists today are much better able to participate effectively in land-use planning than they were in 1970. Planning, execution, and accountability will be bywords for those concerned with land-use planning and wildlife management in the 1980s. Improvements in those abilities should accelerate in the 1980s.

REFERENCES

1. Public Law 91-190. S. 1975, January 1, 1970. National Environmental Policy Act of 1969. 42 U.S.C. sec. 4321, et seq. (1970).
2. Public Law 94-588. S. 3091, October 22, 1976: National Forest Management Act of 1976. 16 U.S.C. sec 1600 (1976).
3. Public Law 91-135. H.R. 11363, December 5, 1969: Endangered Species Conservation Act of 1969. 16 U.S.C. sec. 668 (1970).
4. Public Law 93-205. S. 1983, December 28, 1973: Endangered Species Act of 1973. 16 U.S.C. sec. 668 (1976).
5. Public Law 93-378. S. 2296, August 17, 1974: Forest and Rangeland Renewable Resources Planning Act of 1974. 16 U.S.C. sec. 1601 (1976).
6. Holbrook, H. L. 1974. A system for wildlife habitat management on southern National Forests. Wildl. Soc. Bull. 6(3):119-123.
7. Siderits, K., and R. E. Radtke. 1977. Enhancing forest wildlife habitat through diversity. Trans. N. Amer. Wildl. and Natur. Resour. Conf. 42:425-434.
8. Thomas, J. W. 1979. Introduction. pp. 10-21 *In* Wildlife habitats in managed forest—the Blue Mountains of Oregon and Washington. J.W. Thomas, ed. USDA Forest Service, Agric. Handb. No. 553. U.S. Gov. Print. Off., Washington, D.C.
9. Flood, B. S., M. E. Sangster, R. D. Sparrowe, and T. S. Baskett. 1977. A handbook for habitat evaluation procedures. Fish and Wildlife Service, USDI. Resour. Publ. 132. Washington, D.C. 77 pp.
10. Whitaker, G. A., E. R. Roach, R. H. McCuen. 1976. Inventorying habitats and rating their value for wildlife species. Presented at the 30th Annual Conf. S. E. Assoc. Game and Fish Commissioners. Multilith. 18 pp.

11. Whitaker, G. A., and R. H. McCuen. 1976. A proposed methodology for assessing the quality of wildlife habitat. Ecol. Modeling. 2:251-272.
12. Willis, R. 1975. A technique for estimating potential wildlife populations through habitat evaluations. Pittman-Robertson Game Manage. Tech. Ser. No. 23. Kentucky Dept. Fish and Wildl. Resour. Multilith 12 pp. Frankfort, Ky.
13. Boyce, S. G. 1977. Management of eastern hardwood forests for multiple benefits (DYNAST-MB). USDA Forest Service. Res. Pap. SE-168. Asheville, N.C. 116 pp.
14. Patton, D. R. 1978. RUN WILD: a storage and retrieval system for wildlife habitat information. USDA Forest Service. Gen. Tech. Rep. RM-51. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo. 8 pp.
15. Thomas, J. W., R. J. Miller, H. Black, J. E. Rodiek, and C. Maser. 1976. Guidelines for maintaining and enhancing wildlife habitat in the Blue Mountains of Oregon and Washington. pp. 452-476 *In* Trans. N. Amer. Wildl. and Natr. Resour. Conf. Wildlife Management Institute, Washington, D.C.
16. Thomas, J. W., ed. 1979. Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. USDA Forest Service Agric. Handb. No. 553. U.S.Gov. Print. Off. Washington, D.C. 511 pp.
17. Reynolds, H. G., and R. R. Johnson. 1964. Habitat relations of vertebrates of the Sierra Ancha Experimental Forest. USDA Forest Service. Pap. RM-4. Rocky Mtn. For. and Range Exp. Stn., Fort Collins, Colo. 16 pp.
18. Salwasser, H., H. Black, Jr., and T. Hanley. 1980. The Forest Service fish and wildlife habitat relationships system. USDA Forest Service, Pac. Southwest Reg. San Francisco, Calif. Typescript 23 pp.
19. Verner, J., and A. S. Boss. (Tech. Coord.). 1980. California wildlife and their habitats: western Sierra Nevada, USDA Forest Service. Gen. Tech. Rep. RSW-37. Pac. Southwest For. and Range Exp. Stn. Berkeley, Calif. *In press*
20. Wischnofske, M. 1977. Wildlife habitat relationships of eastern Washington. USDA Forest Service, Wenatchee National Forest. Wenatchee, Wash. 193 pp.
21. Capp, J., B. Carter, J. Delbert, J. Inman, and E. Styskel. *n.d.* Wildlife habitat relationships of south central Oregon. USDA Forest Service. Portland, Ore. 230 pp.
22. Bowers, W., B. Hosford, A. Oakley, and C. Bond. 1979. Native trout. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. J. W. Thomas and C. Maser, eds. USDA Forest Service. Gen. Tech. Rep. PNW-84. Pac. Northwest For. and Range Exp. Stn. Portland, Ore. 16 pp.
23. Maser, C., J. W. Thomas, I. D. Luman, and R. Anderson. 1979. Manmade habitats. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. J. W. Thomas and C. Maser, eds. USDA Forest Service. Gen. Tech. Rep. PNW-86. Pac. Northwest For. and Range Exp. Stn. Portland, Ore. 39 pp.
24. Maser, C., J. M. Geist, D. M. Concannon, R. Anderson, and B. Lovell. 1979. Geomorphic and edaphic habitats. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. USDA Forest Service. Gen. Tech. Rep. PNW-99. Pac. Northwest For. and Range Exp. Stn. Portland, Ore. 84 pp.
25. Thomas, J. W., C. Maser, and J. Rodiek. 1979. Riparian zones. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. J. W. Thomas and C. Maser, eds. USDA Forest Service. Gen. Tech. Rep. PNW-80. Pac. Northwest For. and Range Exp. Stn. Portland, Ore. 18 pp.

26. Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Edges. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. USDA Forest Service. Gen. Tech. Rep. PNW-85. Pac. Northwest For. and Range Exp. Stn. Portland, Ore. 17 pp.

27. Dealy, J. E., D. A. Leckenby, and D. Concannon. 1980. Plant communities in managed rangelands and their importance to wildlife. *In* Wildlife habitats in managed rangelands—the Great Basin of Southeastern Oregon. J. W. Thomas and C. Maser, eds. USDA Forest Service. Gen. Tech. Rep. PNW-*in press*. Pac. Northwest For. and Range Exp. Stn. Portland, Ore.

28. Mason, W. T., Jr., C. T. Cushwa, L. J. Slaski, and D. N. Gladwin. 1979. A procedure for describing fish and wildlife: coding and instructions for Pennsylvania. FWS/OBS-79-19. Office of Biological Services. Fish and Wildlife Service, USDA. Washington, D.C.

29. Thomas, J. W., R. J. Miller, C. Maser, R. G. Anderson, and B. E. Carter. 1979. Plant communities and successional stages. pp. 22-39 *In* Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. J. W. Thomas, ed. USDA Forest Service. Agric. Handb. No. 553. U.S. Gov. Print. Off. Washington, D.C.

30. Haapanen, A. 1966. Bird fauna of the Finnish forest in relation to forest succession. II. Ann. Zool. Fenn. 3(3):176-200.

31. Navon, D. I. 1971. Timber RAM users' manual. Part I: Smokey Forest case study. USDA Forest Service. Pac. Northwest For. and Range Exp. Stn. Berkeley, Calif. 36 pp.

32. Thomas, J. W., H. Black, Jr., R. J. Scherzinger, and R. J. Pedersen. 1979. Deer and elk. pp. 104-127 *In* Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. J. W. Thomas, ed. USDA Forest Service. Agric. Handb. No. 553. U.S. Gov. Print. Off. Washington, D.C.

33. Thomas, J. W. 1979. Preface. pp. iv-v *In* Wildlife habitat in managed forests—the Blue Mountains of Oregon and Washington. J. W. Thomas, ed. USDA Forest Service. Agric. Handb. No. 553. U.S. Gov. Print. Off. Washington, D.C.

34. Schweitzer, D. L., and C. T. Cushwa. 1978. A national assessment of wildlife and fish. Wildl. Soc. Bull. 6(3)149-152.

35. Schweitzer, D. L., C. T. Cushwa, and T. W. Hoekstra. 1978. The 1979 national assessment of wildlife and fish: a progress report. pp. 266-273 *In* Trans. Forty-Third N. Amer. Wildl. and Nat. Resour. Conf., Phoenix, Ariz. Wildlife Management Institute. Washington, D.C.

DESIGN OF COMPUTERIZED FISH AND WILDLIFE SPECIES DATA BASES BY STATE AND FEDERAL AGENCIES

Charles T. Cushwa and Calvin W. DuBrock

INTRODUCTION

At the beginning of the decade there was no coordinated national, regional or statewide effort to bring together information on aquatic and terrestrial vertebrate and invertebrate species of fish and wildlife in a comprehensive computerized data base. Agencies with fish and wildlife directives were primarily concerned with "featured" species management and inventory or "featured" groups of animals, like waterfowl, anadromous fish, big game, furbearers, and farm game, because much of the fish and wildlife philosophy was oriented toward the early classical works that emphasized game management.[1,2] In addition, prestigious work like the International Biological Program also was functionally oriented. Fish and wildlife information was collected under diverse conditions for a variety of reasons and integrated, as best possible, into a data base to perform comprehensive, complex ecosystem analysis. Results from these early efforts were not very rewarding. It became increasingly evident to the makers of agency policies and decisions, as well as to the Congress, that a piecemeal approach to fish and wildlife data base management constituted partial analysis of the resource. To address this problem, Congress passed new legislation in the late 1960s and early 1970s, which required an ecological perspective for assessing the environmental consequences of major land use and management actions.

This new legislation required consistent and accurate inventories and assessments of fish and wildlife species, populations, and habitats in order to meet multiple user needs.[3] Early efforts to respond to these laws indicated that data was not available for many species, and existing information was scattered in professional journals, museum notes, and research records.[4] It became obvious that the existing data must be gathered in central data bases for effective use in environmental analysis, land use planning and management.

The National Environmental Policy Act of 1969 focused attention on the need for more complete and readily accessible information about wild animal resources. Compiling information on numerous animals in the preparation of environmental impact statements or environmental analyses led to the need to manage information about fish and wildlife in a more cost-effective manner, hence, to design and develop some computerized fish and wildlife species data bases.

The Authors: Dr. Charles T. Cushwa is Senior Wildlife Biologist with the Eastern Energy and Land Use Team (EELUT), Office of Biological Services, U.S. Fish and Wildlife Service, Kearneysville, WV. While with the U.S. Forest Service, one of his major accomplishments included assisting in the design and implementation of the 1975 and 1980 National Assessments of Fish and Wildlife Resources, covering 1.6 billion acres of forest and rangeland.

Mr. Calvin W. DuBrock is an Ecologist with the Eastern Energy and Land Use Team (EELUT) and previously worked as a survey statistician for the U.S. Department of Energy. He presently is involved with developing automated species data bases for wildlife planning and management and has contributed to the development and implementation of many statewide data bases.

During the last decade, several other federal laws also have had an impact on the design and development of fish and wildlife species data bases. These laws include: the Endangered Species Act of 1973, the Forest and Rangeland Renewable Resources Planning Act of 1974, the Federal Land Management and Policy Act of 1976, the Federal Water Pollution Control Act of 1976, and the Soil and Water Resources Conservation Act of 1977.

In 1980, it is no longer practical, without a comprehensive computerized fish and wildlife species data base, to meet information requirements for assessment, inventory, and planning on a national or state scale.[5] Also, the concept of managing ecological systems or ecosystems has gained acceptance. Land use management and planning are increasing at all levels of government from local to national. Collectively, these factors have significantly influenced the budget process by allocating additional funds and personnel to improve available fish and wildlife information by designing and implementing numerous state or federal fish and wildlife species computerized data bases.[6]

DESIGN OF FISH AND WILDLIFE SPECIES DATA BASES

One of the major aspects of designing a fish and wildlife species data base is the identification of fish and wildlife information needs; that is, who needs what types of data, in what format, and for what purposes. For example, biologists frequently need information that is too detailed for land managers and policy administrators. On the other hand, administrators and managers must have fish and wildlife information that enables them to meet legal, policy, and bugetary directives at several levels regarding differing land uses and ownership (Figure 1). The basic question is, "Can we design a fish and wildlife species data base that will meet the information needs of the biologist, resource manager, and administrator at different levels of decision-making concerning lands (terrestrial and aquatic) used differently and owned by different groups?"

The design of fish and wildlife species data bases involves four basic factors.

First, many of the fish and wildlife information needs of biologists, managers, and administrators can be answered by asking the following questions:

- What animals are present (diversity and distribution) and how many are there (quantity)?

In Designing Fish and Wildlife Species Data Bases			
Different Users/ Decisionmakers	Require Information at Different Levels	On Land Owned By	And Used for a Variety of Purposes
Administrators	International	Federal	Range
Planners	National	State	Forest
Managers	Regional	County	Urban
Researchers	State	City	Industrial
Educators	County	Private	Farming
Public	Site		Transportation
Others	Habitat Type		Energy
	Others		Others

Figure 1. Factors influencing the design of fish and wildlife species data bases.

- What do the animals require (species-habitat relationships)?
- How much habitat is available and what is its value?
- Where is the habitat located?
- How do the animals respond to alternative land uses and management practices?
- What management practices will produce the desired population response?

Secondly, the institutional complexity of fish and wildlife resources influence the design of species data bases. For example:

- The states own resident fish and wildlife and are legally responsible for their animals.
- The states define "wildlife" differently.
- The federal government is legally responsible for the protection and management of migratory, threatened, or endangered species, and for species involved in international treaties.
- The habitat of wild animals is owned and managed by individuals, cooperatives, local, state, and federal agencies.

Thirdly, the design of fish and wildlife species data bases is influenced by the complexity of the resource. For example:

- The fish and wildlife resource is comprised of over 4,000 species of vertebrate wild animals and tens of thousands of species of invertebrate animals within the United States.
- These species occupy a complex variety of aquatic and terrestrial habitats including the surface and near surface environments of the entire United States.

Fourthly, the design of fish and wildlife species data bases is influenced by the availability, format, and completeness of information about a species or group of animals.

- Much of the available information is historical and scattered throughout many files, reports, books, and unpublished notes.

In order to consider the above four factors in the design of a fish and wildlife species data base, an interagency team or steering committee approach is recommended (Figure 2). For example, it is impossible to identify an individual or agency who is expert on all taxa of fish and wildlife inhabiting the United States, or one who knows all of the institutional ramifications and information needs of managers, planners, and administrators.

This approach (Figure 2) has merit because the steering committee: (1) addresses complex institutional questions concerning legal responsibility, funding, data base management and other maintenance needs, (2) identifies and coordinates principal user needs, (3) provides for uniform, consistent data expressions, and (4) provides a framework for tracking data dissemination. These are just a few of the advantages of the steering committee approach to species data base implementation.

COMPUTERIZED FISH AND WILDLIFE SPECIES DATA BASE DEVELOPMENTS IN THE 1970s

U.S. Environmental Protection Agency (EPA)

The EPA started building a national species data base, called BIO-STORET, in the mid-1970s to meet some of the information needs of the Federal Water Pollution

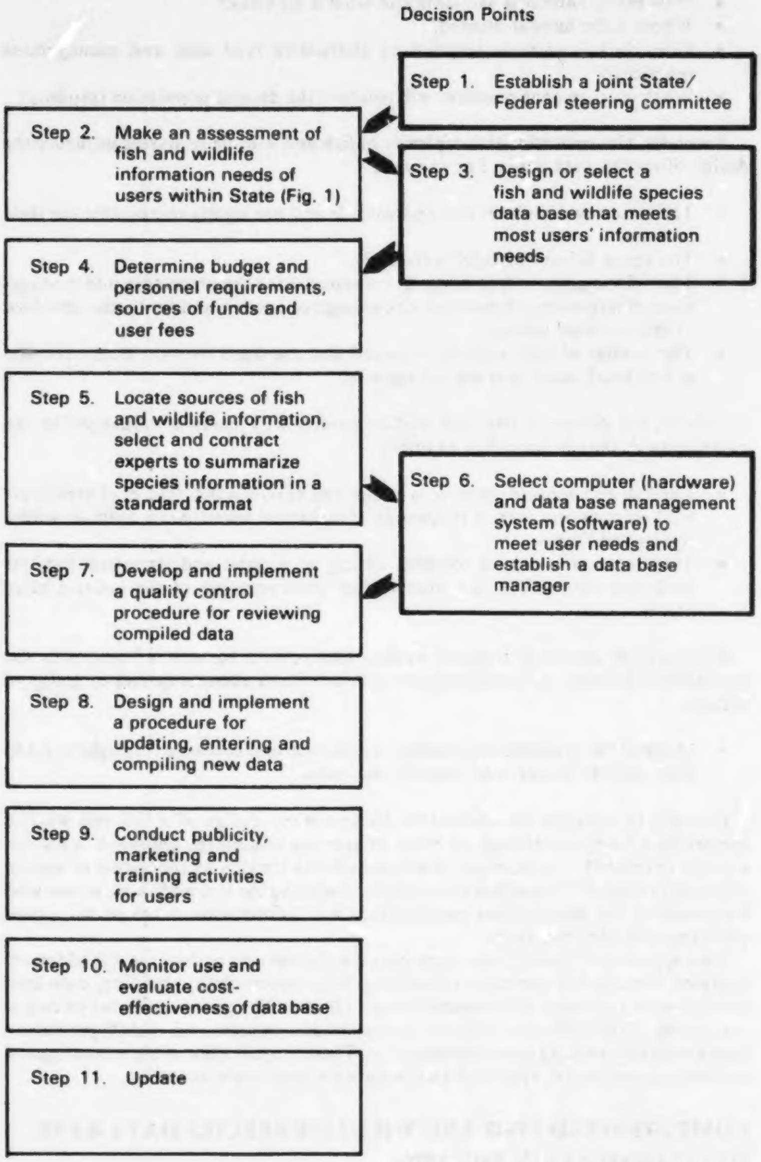

Decision Points
Step 1. Establish a joint State/ Federal steering committee
Step 2. Make an assessment of fish and wildlife information needs of users within State (Fig. 1)
Step 3. Design or select a fish and wildlife species data base that meets most users' information needs
Step 4. Determine budget and personnel requirements, sources of funds and user fees
Step 5. Locate sources of fish and wildlife information, select and contract experts to summarize species information in a standard format
Step 6. Select computer (hardware) and data base management system (software) to meet user needs and establish a data base manager
Step 7. Develop and implement a quality control procedure for reviewing compiled data
Step 8. Design and implement a procedure for updating, entering and compiling new data
Step 9. Conduct publicity, marketing and training activities for users
Step 10. Monitor use and evaluate cost-effectiveness of data base
Step 11. Update

Figure 2. A process for desigining, implementing, and managing a statewide fish and wildlife species data base to meet the information needs of the biologist, resource manager, and administrator.

Control Act. BIO-STORET originated in the Methods Development Laboratory of the EPA, Cincinnati, Ohio, in the early 1970s.[7] The system was developed as a repository for field and laboratory biological data being collected by EPA and others for water quality monitoring. The BIO-STORET program currently being operated by EPA includes information about freshwater and marine organisms, including phytoplankton, zooplankton, periphyton, macrophyton, microinvertebrates, macroinvertebrates, and vertebrates. The system interfaces with the physical and chemical water quality data storage and retrieval system (STORET), developed in the early 1960s to assist with implementation of the Federal Water Quality Act.

BIO-STORET includes: a hierarchical classification of all freshwater and coastal species; distribution categories such as watershed and Office of Water Data Coordination hydrologic cataloging units; state and county information and latitudinal and longitudinal data. A data base management system (System 2000) manipulates the taxon, dates of collection, sampler type, location, standard biomass units and many other environmental factors. BIO-STORET is operational and has been tested in the Great Lakes, and the Ohio and Savannah Rivers.

U.S. Forest Service (FS)

The Forest Service, in response to the legislative requirements of the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 and the National Forest Management Act (NFMA) of 1976, developed a national fish and wildlife species data base to facilitate the periodic assessment of all fish and wildlife resources on the Nation's forests and rangelands. RPA/NFMA assessments are to define future demand for and prospective supplies of fish and wildlife resources and opportunities to moderate or avoid imbalance.

The 1975-80 FS national assessment of fish and wildlife resources asked each state for standardized information on the number of hunters and anglers as well as the number of animals harvested.[4,8] Before this 1980 assessment, data needed to support a national assessment either did not exist or had not been compiled. For example, there were no comprehensive state lists of either resident or common migrant vertebrate species; no consistent definitions of fish and wildlife habitat; no estimates of the extent and distribution of wildlife habitat; and no demand or supply information for more than 40 species inhabiting a state. The average was less than 15 species per state.[9]

The 1980 RPA fish and wildlife data base contains the following information by species: demand; supply; species-habitat relations including scientific names, legal status, species associations with major vegetation and aquatic types within each of the states. This data base includes information on approximately 3,000 vertebrate species and is operational at the USDA Computer Center, Fort Collins, Colorado.

As a result of the RPA national fish and wildlife data base, a series of regional or statewide fish and wildlife data bases have been, or are being, developed by the FS.[6]

U.S. Bureau of Land Management (BLM)

The Federal Land Policy and Management Act (FLPMA) of 1976 specifically directs BLM to "...prepare and maintain on a continuing basis an inventory of all public lands and their resources and other values . . ." FLPMA defines fish and wildlife development and utilization as one of the six major uses on public lands. The BLM is conducting resource inventories on approximately 20 million acres of western rangelands. Fish and wildlife habitats on BLM administered land are being mapped and measured in terms of homogeneous units of existing vegetation and special habitat features such as caves, cliffs, and seeps.[3] Vertebrate species data from each inventory is being compiled as part of an overall BLM resource data base. Their data base is maintained at the Service Center, Denver, Colorado.

U.S. Soil Conservation Service (SCS)

The Soil and Water Resources Conservation Act (RCA) of 1977 has provided the opportunity for SCS to conduct broad appraisals of fish and wildlife habitat. RCA requires periodic assessment of the status and condition of all non-federal lands including farmlands, mined land, cropland, pasture land, wetlands, forestland, rangeland, and flood prone areas. The 1979 national appraisal was based on available data from the 1977 SCS Natural Resources Inventory and did not include fish and wildlife data. A fish and wildlife data base is being developed for the 1985 appraisal. Activities concerning this fish and wildlife data base are coordinated through the Office of the Chief Biologist, Washington, D.C.[3]

U.S. Fish and Wildlife Service (FWS)

The Endangered Species Act of 1973, the Clean Water Act of 1977, the National Environmental Policy Act of 1969, and the Surface Mining Control and Reclamation Act of 1977 (SMCRA) are some of the federal laws that have recently influenced the design and development of computerized fish and wildlife species data bases within the FWS. In addition, the Fish and Wildlife Coordination Act of 1958 and several migratory bird treaties also have influenced development of species data bases. As of 1980, seventeen computerized fish and wildlife species data bases were identified within the FWS.[6] Fourteen were operational and three were being developed. Four of the 14 operational data bases included information on both vertebrates and selected invertebrates and three of these four were developed as comprehensive statewide fish and wildlife data bases. The remaining 10 operational data bases include only birds. The statewide species data bases were developed to provide fish and wildlife information needed to meet the requirements of SMCRA. These data bases contain information on 1008, 824, and 844 species of resident and common migrant vertebrates and selected invertebrates in the States of Alabama, West Virginia, and Pennsylvania, respectively.[6,10,11] These prototype efforts involved extensive cooperation among state and federal agencies. The basic methodology developed during these pilot-tests is being further tested and implemented in seven additional states. Specific information on FWS data bases is available from the U.S. Fish and Wildlife Service, Washington, D.C., and the Migratory Bird and Habitat Research Laboratory, Laurel, Maryland.

Statewide Data Bases

One of the first efforts to develop and implement statewide fish and wildlife species data bases involved the FS, BLM, and other interest groups. This data base, called RUN WILD,[12] included 724 species of vertebrates in Arizona and New Mexico. This marked a major breakthrough in the development of computerized fish and wildlife species data bases. This was the first interactive, totally contained system designed primarily to meet the fish and wildlife information needs of managers and planners. The RUN WILD system has been operational for approximately six years in Arizona and New Mexico. It is a classic example of joint federal/state cooperative efforts to compile and manage information about fish and wildlife species.

Through another state/federal cooperative effort in the late 1970s, Thomas and his coworkers designed and implemented a wildlife data base for birds and mammals that inhabit the forests of the Blue Mountains of Oregon.[13] This system is now computerized and is being expanded to include other organisms that inhabit forest and rangeland communities.[14]

The Nature Conservancy has developed data bases in 28 states that include some information on fish and wildlife. These Natural Heritage data bases contain inventories of animals of special interest, summaries describing their life history, references, and reference maps showing where these animals can be found.[6,15]

In 1979, Besadny summarized states' efforts to develop fish and wildlife data bases.[16] He concluded that: (1) efforts were not coordinated among federal and state natural resource agencies, and (2) there were no regional or national standards for the collection, storage or retrieval of fish and wildlife inventories. Besadny recommended a standardized inventory/assessment procedure and a computerized data storage bank, developed cooperatively by state, federal, and private organizations. To date, Besadny's recommendations have not been followed, that is, coordination of fish and wildlife species data base activities has been very limited.[6,17] However, some progress has been made. For example, five federal agencies (BLM, SCS, FS, FWS, and the U.S. Geological Survey) have signed an interagency agreement related to classifications and inventories of natural resources.[18] This group, in cooperation with the International Association of Fish and Wildlife Agencies and the Association of State Governments, established a state/federal cooperative group to increase emphasis on fish and wildlife classifications and inventories. This 5-Way Group also appointed a work group to develop a national standard list of fish and wildlife species names.

The Next Decade

New opportunities in natural resource management, planning, and research opportunities lay ahead in the 1980s because of the progress made during the 1970s in developing and implementing computerized fish and wildlife species data bases (Figures 3 and 4). Natural resource managers will be able to examine an entire array of fish and wildlife species at different life stages in different habitats using computerized fish and wildlife data bases. Also, they will be able quickly to examine

Figure 3. A Wildlife biologist prepares a species description. The volumes of information on species life histories are coded for computer by various categories, such as distribution, habitat associations, food habits, life environmental requirements, management practices, and other useful background information.

Figure 4. The fish and wildlife species information is retrieved by computer in a cross-index manner to facilitate aggregation of information to aid in planning and management decisions.

how changes in habitats affect species distribution, abundance, and diversity. They will be able to simulate, *a priori*, the impacts of alternative land use and management decisions on an entire animal community. Research organizations will be able to identify major gaps in the state of knowledge of specific animals or groups of animals. Additional applications will include: providing baseline data for environmental impact assessments, land use planning, and species inventories; mining and water permit preparation and evaluation; and environmental education and extension summaries. Species data bases will be coupled with geographic information systems and other computer graphics packages to generate species distribution maps, diversity indices maps, and the like.

During the 1980s, fish and wildlife species data bases will be used to enhance our knowledge and expertise in ecological analyses such as food webs and ecosystem effects due to changing land use practices. Site-specific management objectives for fish and wildlife will be aided by the use of both computerized species data bases and graphic capabilities. The next decade we should see the development of more advanced, efficient data bases and information systems that will expedite our natural resource planning and management functions.

To facilitate data exchange and cost-effectiveness, we need to concentrate efforts during the 1980s on coordinating state and federal efforts to establish data bases, standardize data element classifications, definitions, and habitat classification schemes used in data bases, and to evaluate and update existing systems. These are some of the exciting challenges of the next decade.

REFERENCES

1. Gottschalk, J. S. 1975. The challenge of practical ecology. Keynote address. pp. 2-5. *In* Proc. Symp. of Manage. of Forest and Range Hab. for Nongame Birds. GTV WOI. Forest Service, USDA. Washington, D.C. 343 pp.
2. Bertran, G. A., and L. M. Talbot. 1978. Preface to Wildlife and America. 041-011-00043-2. U.S. Govt. Printing Office. Washington, D.C. 532 pp.
3. Hirsch, A., W. B. Krohn, D. L. Schweitzer, and C. H. Thomas. 1979. Trends and needs in federal inventories of wildlife habitat. pp. 340-359. *In* Trans. Forty-Fourth N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.
4. Schweitzer, D. L., C. T. Cushwa, and T. W. Hoekstra. 1978. 1979 national assessment of wildlife and fish: a program report. pp. 266-273. *In* Trans. Forty-Third N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.
5. Cushwa, C. T., C. W. DuBrock, N. D. Gladwin, G. R. Gravatt, R. C. Plantico, R. N. Rowse, and L. J. Slaski. 1980. A procedure for describing fish and wildlife for Pennsylvania: summary evaluation report. FWS/OBS-79/19A. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 15 pp.
6. DuBrock, C. W., D. N. Gladwin, W. T. Mason, Jr., and C. T. Cushwa. 1981. State-of-the-art of fish and wildlife species information systems in the United States. pp. 156-170. *In* Trans. Forty-Sixth N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.
7. Weber. C. I., and C. D. Silver. 1978. BIO-STORET master species list. 2nd edition. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency. Cincinnati, Ohio.
8. Schweitzer, D. L., and C. T. Cushwa. 1978. A national assessment of wildlife and fish. Wildl. Soc. Bull. 7(3):149-152.
9. Hoekstra, T. W., D. L. Schweitzer, C. T. Cushwa, S. H. Anderson, and R. B. Barnes. 1979. Preliminary evaluation of a national wildlife and fish data base. pp. 380-391. *In* Trans. Forty-Fourth N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.
10 Mason, W. T., Jr., C. T. Cushwa, L. J. Slaski, and D. N. Gladwin. 1979. A procedure for describing fish and wildlife: coding instructions for Pennsylvania. FWS/OBS-79/19. 2 Vol. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 21 pp.
11. Cushwa, C. T., D. R. Patton, W. T. Mason, Jr., and L. J. Slaski. 1978. A computerized data system for fish and wildlife resources. pp. 59-65. *In* Trans. 35th Northeast Fish and Wildl. Conf. White Sulphur Springs, W.V.
12. Patton, D. R. 1978. RUN WILD, a storage and retrieval system for wildlife habitat information. Gen. Tech. Rep. RM-51. Forest Service, USDA. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.
13. Thomas, J. W., ed. 1979. Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. Agric. Handb. No. 553. U.S. Govt. Printing Office. Washington, D.C. 512 pp.
14. Thomas, J. W. 1981. (In this Monograph).
15. Anonymous. 1978. The West Virginia heritage trust program alternatives for the future: the application of heritage data to the planning process. The Nature Conservancy. Arlington, Va. 29 pp.
16. Besadny, C. D. 1979. State efforts to inventory wildlife habitat. pp. 360-368. *In* Trans. Forty-Fourth N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.
17. Cushwa, C. T. 1979. Coordination wildlife habitat inventories and evaluations. Opening remarks. pp. 337-339. *In* Trans. Forty-Fourth N. Amer. Wildl. and Natur. Resour. Conf. Wildlife Management Institute. Washington, D.C.

18. Anonymous. 1978. Interagency agreement related to classifications and inventories of natural resources. Forest Service and Soil Conservation Service, USDA; Bureau of Land Management, Fish and Wildlife Service, and Geological Survey, USDI. Washington, D.C. 44 pp.

MANAGING COASTAL ECOSYSTEMS: PROGRESS TOWARDS A SYSTEMS APPROACH

James B. Johnston

INTRODUCTION

Coastal ecosystems, which include uplands, river mouths, bays, estuaries, and wetlands, are extremely important because they provide major transportation routes for commerce, essential habitats for fish and wildlife resources, and a source of recreational opportunity for more than eighty percent of the population of the United States.[1] Commercial fishing, sport fishing, game and waterfowl hunting, and other wildlife-related activities are affected by the biological conditions of the bays and estuaries. For example, 60 to 80 percent of our commercial finfishes and shellfishes are estuarine dependent; they require estuaries for breeding, nursery, or feeding purposes. The commercial catches of the major estuarine-dependent finfishes and shellfishes in 1977 and 1978 had dockside values of 1.7 billion dollars and 1.3 billion dollars, respectively.[2]

Wetlands provide food and cover for waterfowl, wildlife, and sport and commercial fish. Waterfowl depend on wetlands for breeding and wintering habitat, particularly along migratory routes. Wetlands also can retain flood waters and trap pollutants. Despite these ecological values, the areas of wetlands have been drastically reduced. The wetland loss rates for the continental United States were estimated to be 0.2 percent per year (8,200 ha per year) between 1922 and 1954, and 0.5 percent per year (19,000 ha per year) from 1954 to mid-1970, utilizing existing wetland inventories conducted by state and federal agencies.[3] Losses are directly attributed to dredging, draining, and filling, and to storms, subsidence and erosion.

Recognizing the importance of and damage inflicted to coastal ecosystems, the U.S. Fish and Wildlife Service's Coastal Ecosystems Project (cosponsored by the Environmental Protection Agency under its initial Interagency Energy-Environment Research and Development Program) has developed a system or holistic concept for synthesizing ecological information for use in managing coastal ecosystems. These studies are called coastal ecological characterizations. Voluminous data are compiled and synthesized to provide ecological data bases for large coastal regions.

Over the last five years, the U.S. Fish and Wildlife Service for the U.S. Environmental Protection Agency has conducted characterization studies of the Chenier Plain of Louisiana and Texas,[4] the Pacific Northwest (Washington and Oregon),[5] the Rocky Coast of Maine,[6] and the Sea Islands Coastal Region of Georgia and South Carolina[7] (Figure 1) to assist natural resource managers of these areas in fulfilling their legislative mandates. Current studies are being conducted by the U.S. Fish and Wildlife Service for the Bureau of Land Management to address nearshore and onshore impacts associated with Outer Continental Shelf (OCS) oil and gas

---

The Author: Dr. Johnston is a Marine Ecologist, for the U.S. Fish and Wildlife Service, Dept. of the Interior, National Coastal Ecosystems Team, Slidell, LA. He has served as an Oceanographer (Marine Biologist), for the Bureau of Land Management, Dept. of the Interior, LA (1974-1976). He has published numerous papers on coastal zone management, Outer Continental Shelf oil and gas development, fisheries, environmental education, and ecological characterizations.

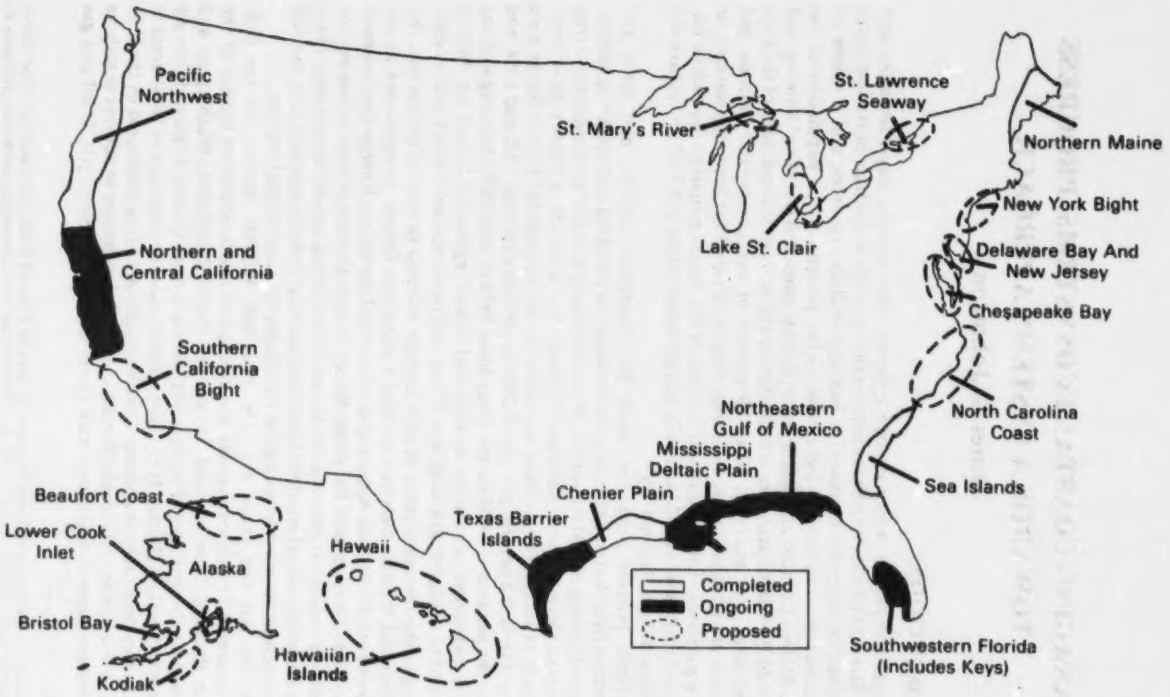


Figure 1. Location of coastal ecological characterization studies (adapted from Terrell 1979).[a]

activities. Results will be applicable to resolving numerous resource conflicts in the coastal zone.

Characterization studies, which were initiated early in 1976, have become a primary means of expanding our ecological information base and increasing our knowledge and understanding of coastal ecosystems so that improved methods of environmental impact assessment and management can be developed. These studies also provide a link between separate studies of the continental components of ecological systems and their oceanic interfaces.[8]

Other efforts similar to characterization studies have been conducted by numerous agencies during the 1970s for coastal ecosystems. Examples of these projects include the study of the New York Bight by the National Oceanic and Atmospheric Administration, the Potomac Estuary Study by the Maryland Department of Natural Resources' Power Plant Siting Program, a study of South Florida by the University of Florida's Center for Wetlands, and a study of Puget Sound by the State of Washington.

COASTAL ECOLOGICAL CHARACTERIZATION STUDIES

Definition

Most previous ecological studies of coastal ecosystems have focused on facets of the system, either its geographic areas (states, counties, floodplains) or various biological, geological, physical, and social components (e.g., animals, populations, land uses, habitats, and water regimes). These efforts provide data and information that lead to new insights concerning the particular ecological components studied, but the interrelationships of these components and their processes have not been adequately analyzed holistically.

Therefore, confusion and debate exist among decisionmakers about problems, possible solutions, and the future status of coastal ecosystems. In response, coastal ecological characterization studies are designed to provide a holistic, structured synthesis and analysis of existing information from the biological, physical, social, and economic sciences. Characterization studies are tailored to meet the needs of a wide range of decisionmakers and are designed to be useful for environmental protection and planning.

Major sources of information are incorporated into characterization studies, including such materials as: 1) published maps, reports, and scientific journals; 2) personal files and unpublished data; and 3) computer data files from federal, state, university, and private institutions. Some data are inaccessible and vary in quality and form. The data range from short-term records noting the presence or absence of species, to exhaustive quantitative estimates of densities over both time and space. Characterization studies are a means of integrating these various types of data by describing or illustrating them in terms most useful to natural resource managers and planners of the U.S. Fish and Wildlife Service, Environmental Protection Agency, Bureau of Land Management, other federal and state organizations, and to members of local agencies or the general public.

PRODUCTS AND DATA BASES

Ecosystems (Conceptual) Models

The ecosystem models or conceptual framework of characterization studies, in verbal or graphic form, delineate and define key physical processes, biological resources, socioeconomic features, functional relationships, and the forces that influence them. Although these models represent a systematized framework for data collection and analysis, models ultimately must be statistically and mathematically correct within certain confidence intervals if accurate quantitative assessments or predictions are to be made. Figure 2 depicts an emergent wetland (marsh) community in a wetland habitat with a wetland energy-circuit model superimposed.[3] Both

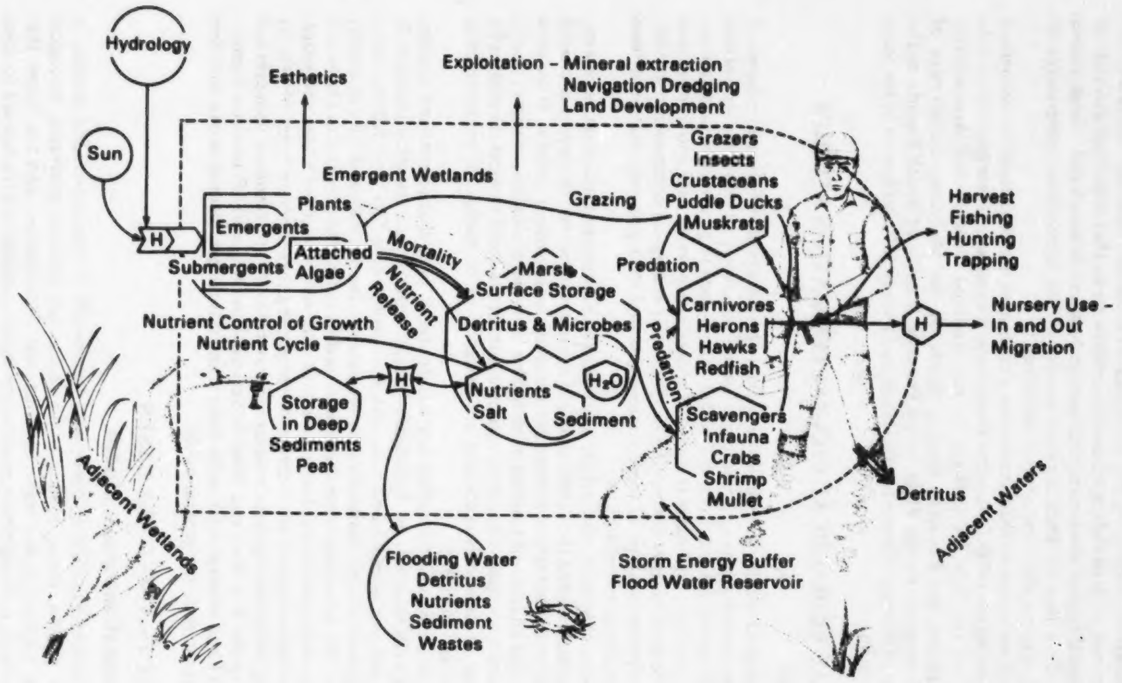


Figure 2. A wetland energy-circuit model superimposed on a sketch of an emergent wetland.[4]

illustrate the same processes, components, and interrelationships. The energy circuit diagram is more academic, but the sketch is more easily understood. Characterization studies include both types of graphics and combinations of them with narrative explanations.

In summary, the models with accompanying narrative and graphics are designed to delineate functional system boundaries, forcing functions (such as climate, tides, and currents); components (such as habitats, populations, and species); processes (such as energy transfer, sedimentation, and food webs); and economic productivity (such as commercial fishing, hunting, oil and gas production, and industrial development).

Narrative Report

The narrative report of a characterization study complements the ecosystem (conceptual) models by more fully explaining the cause and effect relationships of human activities, natural changes, and their controlling influences. The report contains a narrative, figures, tables, and diagrams. It also includes a user's guide to assist the reader in understanding how to obtain maximum benefits from the report. Examples of the type of data presentations used in the report are shown in Figures 3 and 4. Figure 3 illustrates a generalized secondary plant succession in white pine and shrub pine forests and its associated bird species for coastal Maine.[6] Figure 4 depicts a typical coastal ecosystem trophic structure and food web.[9]

Ecological Atlas

The ecological atlas consists of maps with supporting narrative and tabular data that depict biological resources, coastal processes, socioeconomic activities, physical features, and hydrologic information. Map scales vary from 1:24,000 to 1:1,000,000, depending upon the topic portrayed. The standard mapping scales are 1:24,000 and 1:100,000, using U.S. Geological Survey topographic series as base maps. The types of information used, topics portrayed, and uses of maps are shown in Figure 5.

The maps show biological resources, including oyster and clam beds, fish spawning and nursery areas, submerged vegetation, nesting and high density areas for birds and sea turtles, high density areas of waterfowl and furbearers, critical habitats for endangered and threatened species, natural or artificial fishing reefs, and habitats. For some study areas, habitats (wetland and upland) are portrayed at a scale of 1:24,000 for both past (1950s) and present (late 1970s) distribution.

For example, data for the habitat maps of the Mississippi Deltaic Plain Region study indicate that over 500,000 acres, or 800 square miles of southeastern Louisiana coastal wetlands were lost or altered from the mid-1950s to 1978. This represents an approximate rate of about 25,000 acres, or 39 square miles, per year. The majority of the wetland changes was from marsh to open water. The loss or alteration in Mississippi, which has less wetland area, was estimated at 5,500 acres, or less than nine miles, during the two decades.

Physical features that have been mapped are shoreline changes, high and low wave energies, and inundations by major hurricanes and storms. Boundaries of fresh and nonfresh (saline) marshes in the 1950s, 1960s, and 1970s and water control structures, including dams, locks, and weirs, have also been mapped.

Socioeconomic features that have been portrayed are conservation, preservation, and recreation areas, point source discharges, energy developments such as oil and gas infrastructure including pipelines, mineral resources, dredge spoil disposal sites, and historical and archaeological sites.

Some maps also show geological features, spoil areas, active dunes, currents, seasonal wind patterns, and estuarine circulation patterns.

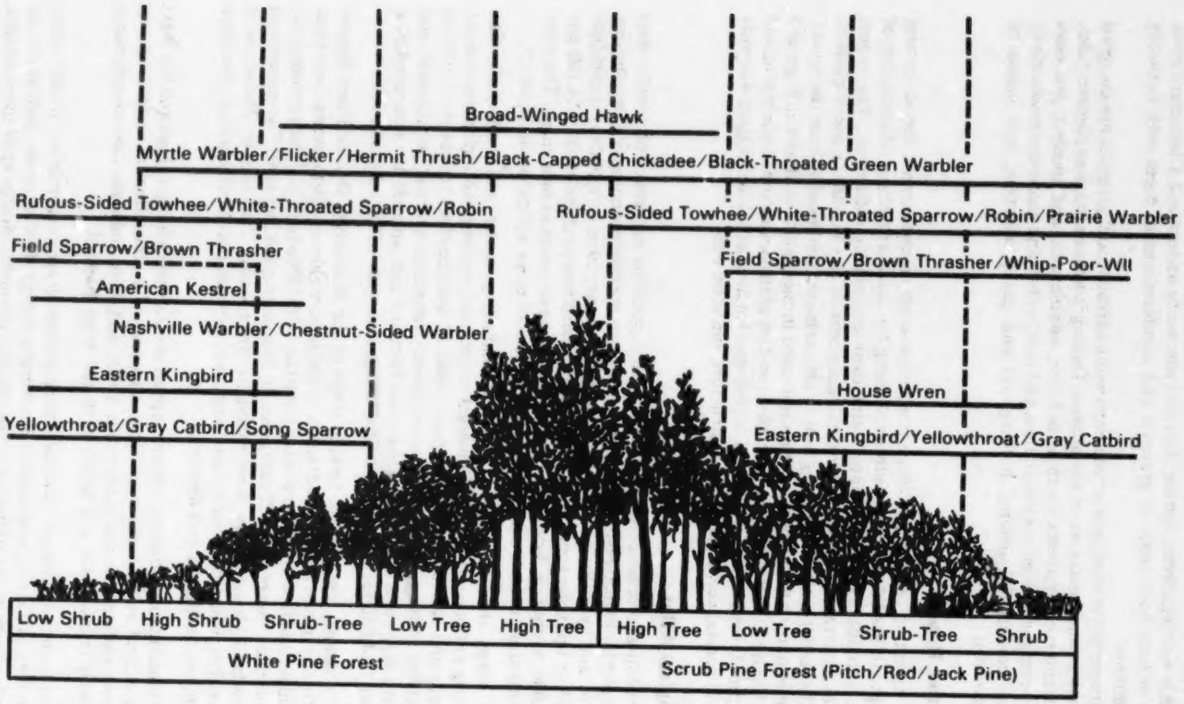

Broad-Winged Hawk
Myrtle Warbler/Flicker/Hermit Thrush/Black-Capped Chickadee/Black-Throated Green Warbler
Rufous-Sided Towhee/White-Throated Sparrow/Robin
Rufous-Sided Towhee/White-Throated Sparrow/Robin/Prairie Warbler
Field Sparrow/Brown Thrasher
Field Sparrow/Brown Thrasher/Whip-Poor-Wil
American Kestrel
Nashville Warbler/Chestnut-Sided Warbler
Eastern Kingbird
House Wren
Yellowthroat/Gray Catbird/Song Sparrow
Eastern Kingbird/Yellowthroat/Gray Catbird
Low Shrub
High Shrub
Shrub-Tree
Low Tree
High Tree
High Tree
Low Tree
Shrub-Tree
Shrub
White Pine Forest
Scrub Pine Forest (Pitch/Red/Jack Pine)

Figure 3. Generalized secondary plant succession and associated bird species in white pine (left half) and shrub pine (right half) forests. Height of the vertical lines does not reflect the birds preferred strata.[6]

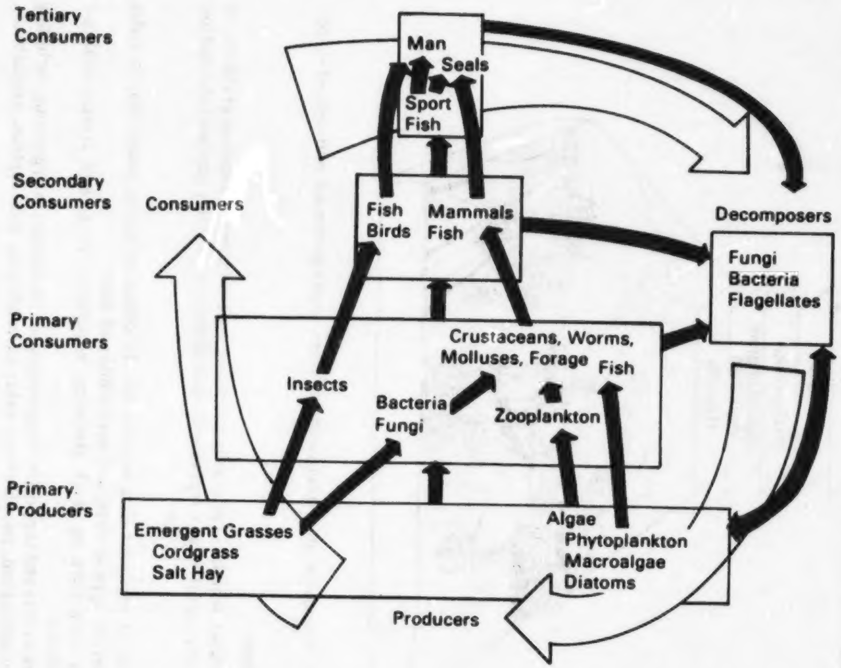


Figure 4. Ecosystem trophic structure and food web. Arrows indicate general energy a material flow (modified from Jones and Stokes Associates, Inc. 1980).

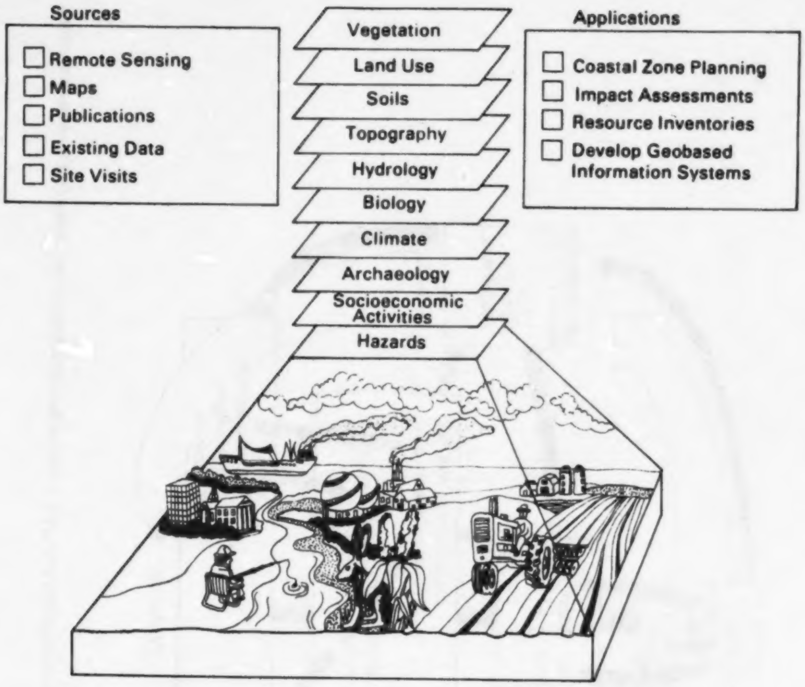


Figure 5. Ecological atlas information sources, topics portrayed, and uses of maps.

Appendices

Appendices, which are primarily narrative, are contained in a section at the end of the narrative report or as a separate volume of the report. They contain information such as:

- a list of pertinent data sources for the characterization study that includes location, type of data, and accessibility of data
- raw data such as catch statistics, population data, and recreational use statistics
- species lists and supportive information about numerous organisms, including phytoplankton, zooplankton, other invertebrates, fish, reptiles, amphibians, birds and wetland plants
- documentation of the modeling approach
- a description of legislative structure pertinent to the study area
- a description of data gaps or research needs most essential for greater understanding of the region, subsystems, habitats, and populations and species.

Computerized Support Systems

MANAGE is a general-purpose data base management software system that gives users access to an integrated collection of text and tabular data. A set of interactive commands is utilized to store, retrieve, and display data from an ecological characterization data base. Types of data bases developed from characterization studies that utilize MANAGE include bibliographical materials, habitat data (area measurements), species lists, water quality measurements, economic statistics, and biological data on animals and wetland plants.

The WAMS (Wetland Analytical Mapping System) software system produces digital representation of spatial data in degrees of longitude and latitude. This enables the user to concentrate a number of maps into a single geographic information system. Large data bases can be created and maintained with WAMS and a verification process insures spatial consistency in the data that have been collected. Primary characterization products utilizing WAMS are habitat maps (1:24,000) from the 1950s and 1970s, and biological resources, physical features, and socioeconomic maps (1:100,000).

The MOSS (Map Overlay Statistical System) software system interactively stores digital map files, activates analysis and management procedures for those files, and displays the results as finished products in a variety of formats. Alternative formats display products as maps, map overlays, or tables. The data for MOSS are derived not only from map products in ecological characterization studies but also from statistical data that are in narrative reports and appendices.

All of the above systems will be used to address natural resource planning problems, energy and transportation developments, and impact analyses for coastal ecosystems.

APPLICATIONS

Characterization studies are being used by federal, state, and local agencies, private organizations, and individuals. The following examples illustrate the broad range of applications:

- as supporting documents in conducting lease sales of Outer Continental Shelf (OCS) lands for oil and gas exploration and development in northern and central California, Texas, Louisiana, Mississippi, Alabama, and Florida
- for planning pipeline corridors from OCS areas to onshore facilities in Louisiana and Texas
- for evaluating environmental impacts from offshore mooring facilities and deep water port developments in Oregon and Washington
- in coastal zone management programs by state agencies, specifically Maine, South Carolina, and Louisiana
- to respond to EPA 208 requirements by county/parish governments
- as an information source in delineating areas for the Jean Lafitte National Park in Louisiana
- in design of environmental studies by federal and state agencies for California, Maine, Texas, and Louisiana
- for planning development projects by a Regional Planning Commission in Maine
- in assessing effects of federal projects such as the lower Winyah Bay terminal and the Santee-Cooper Rediversion projects in South Carolina
- as an information source for the U.S. Fish and Wildlife Service's Atlantic and Pacific Coast Ecological Inventories
- in preparing congressional testimony to support protection plans for offshore barrier islands in Mississippi and Louisiana
- in assessing effects of reduced freshwater inflows on estuaries in Louisiana
- for designing a fish and wildlife management plan for the Columbia River (Oregon and Washington) estuary
- for use in university courses in ecology and in fisheries and wildlife management

— in assessing impacts of oil spills such as IXTOC I in Texas.

In view of the variety of applications of the ecological characterization study products, the primary contribution made by these studies appears to be the compilation of diverse kinds of information from widely scattered sources. The reported information is the best available, its sources are verified, and readers are directed to a wide range of related reference materials. Mapped data are presented to facilitate comparative analysis, and the products are accessible on both scientific and technical levels. Workshops are held for concerned federal, state, and local agencies, and others to demonstrate and test the application of characterization products in a "hands on" exercise. Such workshops are also a means by which users can contribute directly to future studies by clarifying their needs for information and making suggestions to improve the quality of usability products.

FUTURE CHARACTERIZATION THRUSTS

The major thrusts of future characterization efforts will focus on: 1) applying ecological characterization information to coastal issues, primarily energy-related; 2) implementing a computerized delivery system for analysis and updating of characterization data; and 3) evaluating and refining the characterization concept and products. Examples of application studies include an evaluation of strategies for minimizing impacts of selected hydroelectric water release regimes of the Santee-Cooper Rediversion Project on downstream natural resources; energy-related use conflicts in the Columbia River estuary (Oregon-Washington); oil and gas activities and their cumulative effects in Galveston Bay (Texas); and cumulative impacts of wetland loss in coastal Louisiana. Other application efforts will be initiated as characterization studies are completed.

SUMMARY

Environmental protection of our coastal ecosystems has been strengthened in recent years with the enactment of several federal laws such as the National Environmental Policy Act of 1969, the Federal Water Pollution Control Act of 1972, the Coastal Zone Management Act of 1972, and the Endangered Species Act of 1973. These laws, together with the River and Harbor Act of 1899 and the Fish and Wildlife Coordination Act amendment, recent presidential directives on barrier islands and wetlands, and the numerous state and local laws, form the framework for the management of coastal ecosystems. If management of these ecosystems is to be based on the best available information, it is imperative that this knowledge be transferred to decisionmakers in a form that is readily accessible and understandable. Characterization studies provide a standardized methodology for acquiring, analyzing, and portraying information and for allowing a more direct comparison of data produced by numerous groups.

REFERENCES

1. U.S. Water Resources Council. 1978. The Nation's water resources, 1975-2000—the second national water assessment. Vol. 1: Summary. Washington, D.C. 86 pp.
2. U.S. Department of Commerce, National Marine Fisheries Service. 1979. Fisheries of the United States. 1978. Curr. Fish. Stat. Washington, D.C. 120 pp.
3. Gosselink, J. G., and R. H. Baumann. 1980. Wetland inventories: wetland loss along the United States coast. Zeitschrift fur Geomorphologie 34:173-187.
4. Gosselink, J. G., C. L. Cordes, and J. W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. FWS/OBS-78/9 through 78/11. 3 vol. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.

5. Procter, C. M., et al. 1980. An ecological characterization of the Pacific Northwest coastal region. FWS/OBS -79/11 through 79/15 - 5 vol. Office of Biological Services, Fish and Wildlife Service, USDI, Washington, D.C.
6. Fefer, S. I., and P. A. Schettig. 1980. An ecological characterization of coastal Maine (north and east of Cape Elizabeth). FWS/OBS - 80/29. 6 vol. Office of Biological Services, Fish and Wildlife Service, USDI, Washington, D.C.
7. Mathews, R. C., F. W. Stapor, C. R. Richter, et al. 1980. Ecological characterization of the sea island coastal region of South Carolina and Georgia. FWS/OBS - 79/40 through 79/45. 6 vol. Office of Biological Services, USDI. Washington, D.C. 30 pp.
8. Terrell, T. T. 1979. Physical regionalization of coastal ecosystems of the United States and its territories. FWS/OBS - 78/80. Office of Biological Services, Fish and Wildlife Service, USDI, Washington, D.C. 30 pp.
9. Jones & Stokes Associates, Inc. 1980. Ecological characterization of the central and northern California coastal region. FWS/OBS - 80/45. 5 vol. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.

ASSESSMENT AND PREDICTION OF EFFECTS OF ENVIRONMENTAL IMPACTS ON FISH AND WILDLIFE HABITAT: OVERVIEW

Kenneth Cummins and Rosanna Mattingly

INTRODUCTION

General Purpose of Overview

Environmental research has recently been defined as "scientific activity undertaken with the primary aim of maintaining, restoring, or improving the environment, or for predicting changes in the environment."[1] Such investigations may be conceptual, empirical, or developmental in nature, and may pertain to either man-made or natural systems. The past decade, largely because of the National Environmental Policy Act (NEPA), has witnessed effects of a national commitment to environmental management. An overview of environmental assessment and prediction is provided in the following, which includes: (1) a survey of commonly used methods of assessment and prediction, (2) an examination of ways in which these methods have been used and evaluation of their effectiveness, and (3) a review of the decade of the seventies with reference to ability to adequately manage fish and wildlife resources particularly via habitat protection and/or alteration. Specific areas are reviewed (wetland ecosystems—Larson; biotoxicology—Gillett and Mount) and presented in detail (instream flow assessment—Stalnaker; the systems approach to environmental management—Holling and Patten) in subsequent sections.

Need for Protection and Management of Animals and Their Habitats

Animals and their habitats require protection and management for a variety of reasons, among which is the continued harvest of species of economic value. Because species alive today provide a repository for valuable raw materials (e.g., genetic stock, biomass), protection could allow future generations an option to utilize species in ways not yet envisioned.

Modification or loss of habitat, primarily from economic development of natural environments has been a principal destructive factor in species extinctions.[2] Although extinctions are inevitable on the geologic time scale, and, in that time, periods of vast extinction have occurred, the observed (and predicted) rate of extinction is believed to have accelerated, primarily because of loss of appropriate habitat due to man's activities. One of innumerable examples is that pre-settlement flood plain forests along the Missouri River were extensive and included frequent mature stands, but flood-plain forest coverage declined from 76% in 1826 to 13% in

---

The Authors: Dr. Kenneth Cummins, Professor of Fisheries at Oregon State University, has conducted research and taught in the field of aquatic ecology at Northwestern, Pittsburgh, and Michigan State Universities. He served as Chairman of the Institute of Ecology Advisory Committee to the National Commission on Water Quality and is Aquatic Editor, Ecological Society of America.

Rosanna Mattingly is a Graduate Research Assistant with research and teaching experience at Michigan State and Oregon State Universities. She has published on point and nonpoint source pollution-related changes in a river ecosystem.

1972 and cultivated land increased during the same period from 18% to 83%.[3] From the 1960 to the 1970 census, land use for settlement increased faster than the population in 82% of U.S. communities.[4] Environmental management that has as its goal securing, restoring, reclaiming, and protecting fish and wildlife habitat is more critical today than ever before, because of mounting pressure on potential habitat from both the increasing human population and the escalating demands of society. Continuation of present land-use trends may result in substantial loss of species and genetic resources within the next few decades.[2] Environmental awareness, concern, and appropriate management may help to ensure that future losses are not entirely by default.

Although appropriate management might facilitate such things as the introduction or re-entry of desired animals, species protection without habitat preservation is unworkable, except in very short-term, unstable situations. Various habitats provide refugia both for animals which are available for recolonization of disturbed areas and for backcrossing with other stocks. Protected habitats may also serve as templates that can be used in returning disturbed areas to more natural states.

Ecosystems (systems of organisms and their respective habitats) are characterized by interrelationships among species and by balances in all aspects, not by any one in particular (Figure 1).[5] Protection could foster the maintenance of dynamic relations within and among ecosystems. This should contribute to their long-term persistence (Figure 2).[6,7,8] Although highly complex and diverse systems are usually considered to be more stable than simple ones, large and unprecedented perturbations imposed by man may prove more detrimental to complex natural systems than to those which are simple.[9] Often the adaptedness and stability of an ecosystem are disturbed by man's intervention. This may necessitate further intervention. In addition to

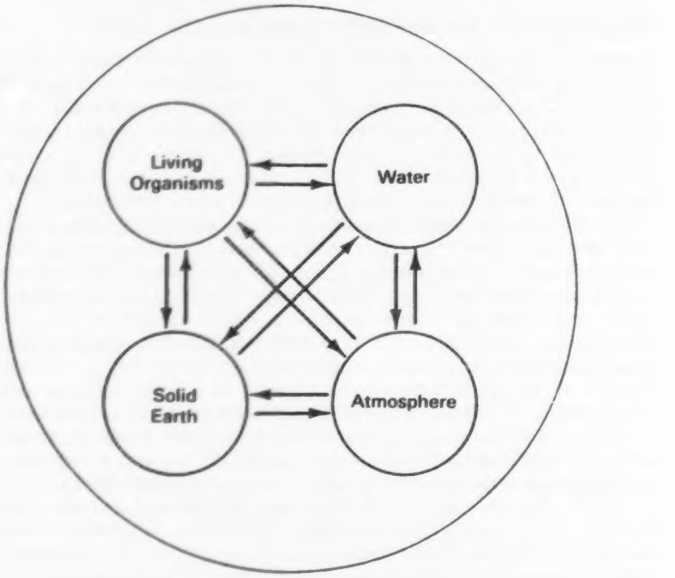


Figure 1. Schematic representation of an ecosystem, characterized by balances in all aspects, not by any one in particular.[5]

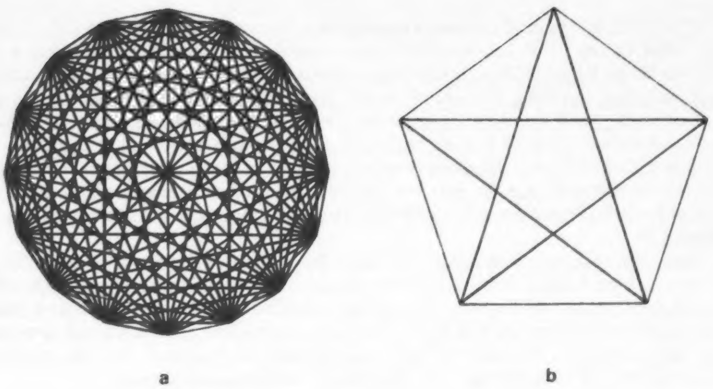


Figure 2. Diagrammatic representation of potential interrelationships between species in two communities : (a) a complex community with a large number of stabilizing interactions, and (b) a simple community with relatively few stabilizing interactions.[5]

practical considerations, numerous aesthetic and ethical concerns, including obligations to future generations and respect for the integrity of the biosphere, are compelling reasons for protecting animals and their habitats.

METHODS OF ASSESSMENT AND PREDICTION

The suitability of available habitat for fish and wildlife, and possible impacts on this habitat need to be assessed in order to predict the effects of potential changes in the resource, whether it is altered or left alone. The ability to manage fish and wildlife resources is generally no better than the tools at hand for assessment and prediction of environmental conditions and organismic responses to these conditions. Uniformity of both approaches to and methods of system-specific assessment and prediction is essential, particularly in studies of a long-term nature.

Legislation can be used to protect and preserve natural resources. This past decade witnessed the birth and development of perhaps today's most widely used tool—the environmental impact assessment process (EIA). Although NEPA does not include specific guidelines for environmental impact statement (EIS) preparation or for public involvement in the process, various federal agencies have developed broad criteria and proposed approaches for public participation. Impact statements serve as guidelines for making decisions by presenting a report of the present and predicted future state of the environment as it might be affected by proposed actions.[10] Development, use, and evaluation of the process have been reviewed in detail.[11,12,13,14,15]

Species diversity indices are often included in environmental impact analyses, and are used as a management tool in their own right. Species lists are useful in describing the status of an ecosystem,[16] but uncritical use of numerical indices assumes too much resolution. The systematics of many groups of organisms remains inadequate for effective use of various species composition indices. In addition, recognition of unnaturally altered ecosystem behavior is obscured by significant natural spatial and temporal variations in biotic communities. Peet,[17] in a comprehensive review of diversity indices, indicates that many indices are but special cases of more encompassing formulations, and suggests that diversity is essentially defined by the indices used to measure it. Various environmental indices are widely used.[18] Assessment procedures frequently involve lengthy and costly biological analyses such as species composition and community metabolism. This has prompted a search for adequate, simple, physical-chemical measurements that chronicle biological events.[19]

Laboratory testing of potentially harmful substances under standardized conditions is another frequently used tool of assessment. Mount and Gillett present the "state-of-the-art" in single species toxicity testing, and note the developing concern for communities as opposed to single important species. The failings of the single species approach are well known.[20] For example, acute toxicity effects have been emphasized, yet these are of limited value in predicting effects of chronic exposure. Guidelines proposed for use of bioassays in determining safe levels of potential toxicants bear little known relationship to the largely unknown consequences of introduction into natural environments.[21]

Other assessment tools include the determination of major controlling variables in an attempt to increase predictability. Commonly used variables include percentage available sunlight, precipitation, and temperature. Given these variables and hypotheses about the way they affect the system of interest, conceptual[19,22] and mathematical[23,24,25] models may be developed to provide predictive power based on the present state of knowledge. In this section, Patten uses a marine ecosystem model to illustrate the importance of indirect as opposed to direct causality factors, and Holling discusses methods and procedures of adaptive environmental assessment and management (AEAM). The latter was developed to integrate disciplines and to bridge gaps between experts and policy designers. Stalnaker reports that research and development relevant to instream flow assessment during the 1970s were primarily directed at physical microhabitat models used to evaluate usability of a resource under different streamflow regimes. Although the "systems approach" is not the "only way to achieve necessary refinements enabling precision and deftness in the attack on environmental problems" (Patten), it nonetheless represents a means of analysis that can be of value when used within its limitations.[26,27]

Classification is an important assessment tool for dealing with the vastly different ecosystems that occur throughout the United States. Some classifications are made according to uses of populations or ecosystems, and thus provide little basis for management. Classifications, such as Bailey's[28] ecoregions, attempt to define and order hierarchical "ecosystems" in ways useful for understanding and management. Franklin's[29] classification for establishing biological reserves and Warren's[30] for classification of watersheds and stream systems are in the latter tradition.

The tools we now have may not be adequate to do the task before us—which is not so much to control the environment as to arrive at enough understanding of basic ecological processes and cycles that proposed steps can be seen and evaluated in light of their impact on ecosystems. Concerted effort is required to ensure that the thoughtful, thorough, and conscientious use of assessment tools be coupled with the wisdom of experienced persons, and that we remain open and receptive to potentially improved methods of analysis. Solutions to fish and wildlife problems need to be based on recognition that environmental management requires not only the information made available through the scientific method, but economic, social, and ethical judgments as well.[31,32]

TRENDS IN ASSESSMENT AND PREDICTION OF EFFECTS OF MAN-MADE IMPACTS ON FISH AND WILDLIFE

Progress during the 1970s in assessment and prediction of man-made impacts on fish and wildlife might be illustrated by major studies. Analysis of relevant case histories alone, however, would neglect almost entirely many efforts that have not yet come to fruition. Changes in attitudes, perception, and awareness have emerged and developed, in part, from national commitment to environmental protection. The following discussion of trends in assessment and prediction of man-made impacts on fish and wildlife represents some of the predominant changes.

Ecosystem Perspective

One shift in thinking that has occurred is from a focus on a given localized habitat, such as a stream reach, old field, or woodlot, toward a more ecosystem-directed approach (e.g., watershed perspective).[33,34] Experiences with air-borne radioactive fallout and air pollution demonstrated the need for broader-based thinking about ecosystems and stimulated environmental awareness and concern for man's impact on other species. Air pollution has even been called a "blessing in disguise" because of its potential to arouse man to achieve a "planned equilibrium with the ecology of earth."[35] Man's impact is ubiquitous—for example, on such divergent systems as climate,[36] barrier islands,[37] and seagrass.[38] The biosphere, i.e., land, water, and air, must be viewed as a whole; solutions to many problems man faces today require this holistic conception (Figure 3).

The rate of loss of animal habitat is increasing, and, in some cases, the habitat is beyond reclamation. Most recent species and population extinctions appear to have resulted from alteration or elimination of habitat—often as the direct result of human settlement and indirectly by species introductions or environmental contamination.[40] Urbanization, wetland drainage, and water impoundments have devastated fish and wildlife habitats. Road building, logging, agriculture, and mining have adversely affected stream organisms, particularly via sedimentation,[41] altered storm water runoff,[42,43] and acid mine drainage.[44,45,46] Land-water interactions are critical features of fish and wildlife habitat. Inputs from the streamside vegetation often constitute the major organic resource for basic food chain elements that support fish populations.[47] Present interest in riparian zones reflects increased awareness during the 1970s of the interdependence of terrestrial and aquatic systems.[48]

Many current land-use practices result in copious loss of water, soil, and plant nutrients.[49] Soil type can affect nutrient concentrations in streams,[50] and fire may enhance nutrient movement in forests as well as atmospheric loads of soluble nutrients.[51,52] Irrigation may result in localized water draw-downs, return-flow problems, increased salinity, and changes in chemical composition. In addition, growth of aquatic macrophytes, which may, among other things, destroy fisheries, interfere with hydroelectric and irrigation schemes, obstruct navigation, and present health hazards and recreational nuisance, is symptomatic of failure to adequately manage resources.[53] Although plant growth can serve as an early warning system for eutrophication of aquatic habitats, it has been the target of widespread use of herbicides. Side effects of environmental contaminants have received much needed attention, but changes in natural nutrient cycles and macronutrients in the atmosphere, soil, and water may have far-reaching consequences. These are due in part to agricultural intensification and deforestation as a whole, as well as to the use of chemicals in agriculture and forestry.[54]

Larson reviews changes in attitudes towards wetlands over the past decade, in which a recognition and appreciation for wetland values has developed. Flood control, storm damage, water quality, fish nurseries, plant productivity, groundwater supply, visual-cultural aspects, and wildlife habitat are all associated with intact wetlands. These changes in attitudes were undoubtedly facilitated by the ecosystem approach.

Man may well be the dam-building animal. Flow regulation has altered water quality,[55] discharge, and thermal regimes through, for example, variations in the stages and timing of flooding.[56] In addition, it has impeded migrations essential for survival of some of the more highly prized fish species.[57,58,59] Instream flow values were not included in legitimate uses of the nation's waters prior to 1968. The 1970s have focused on description of stream reaches and the coupling of measurements of instream flow regimes with such effects as water quality and sediment routing along the stream-river system (Stalnaker).

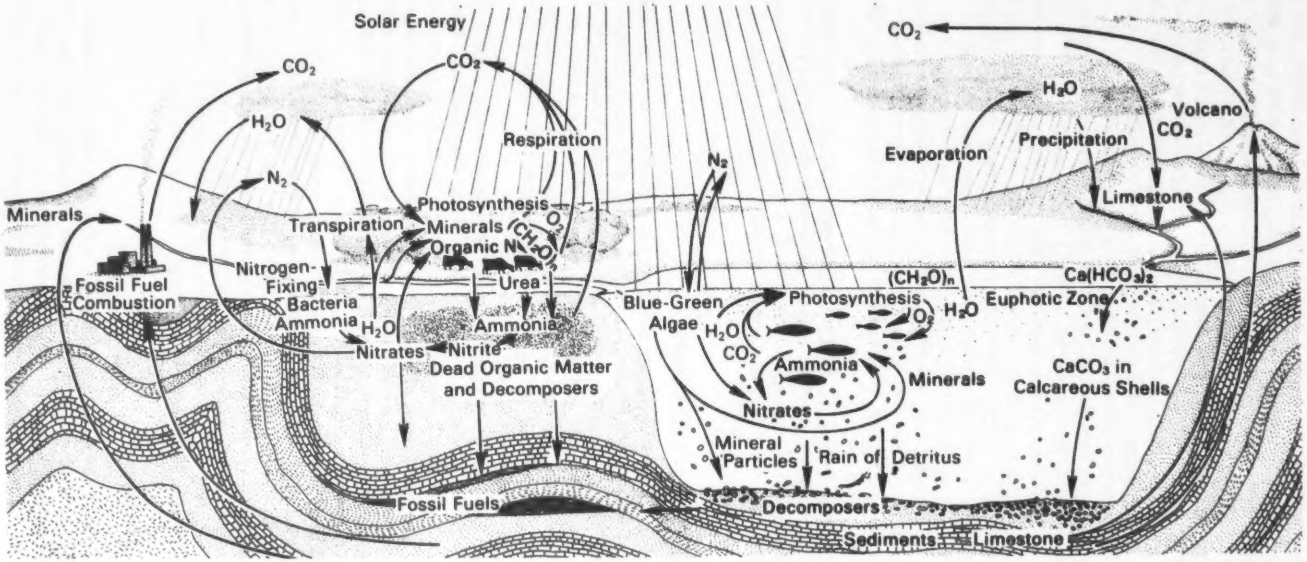


Figure 3. General illustration of major cycles of the biosphere, which depend on utilization of solar energy.[39]

The shift from concern about point source effluents to lakes, rivers, and streams (Public Law 92-500) to nonpoint source run-off (Section 408) in a sense also illustrates a wider perspective. Effects of nonpoint source pollution came to light primarily through efforts to clean up point source problems, which consisted largely of concentrated organic wastes and acutely toxic discharges. Nonpoint source pollution contributed less obvious nitrogen and phosphorus loading, sedimentation, and sublethal or chronic effects of toxins on aquatic organisms. Agricultural land use represents the major nonpoint source influencing most watersheds.[60,61]

Single species, presence/absence, and toxicity tests (described by Mount and Gillett) have often been replaced by approaches that attempt to integrate system properties, e.g., some of the more recent diversity index formulations. Such indices have major shortcomings, yet the approach they represent reflects an increased awareness of the system as a whole. Recent interest in groups of tests[62] and trophic chains,[63] as opposed to single species, as ecotoxicological models for study of ecosystem contamination also stresses this view. Renewed interest in habitat management[64,65,66] and ecosystem protection rather than management of a given population or for a critical species may provide a sounder strategy for management[67] and also illustrates the trend towards the broader ecosystem approach. Many schemes of assessment currently in use concentrate on habitat evaluation rather than resident species censuses.[68]

Failure to consider direct and indirect ramifications of actions and the interrelated components of ecosystems has been in part responsible for the present ecological dilemma. A broader consciousness of relationships inherent in the systems being disturbed is one of the more important emerging features of environmental research and management in the 1970s.

Appreciation of Large Scale Events

Another trend is a developing appreciation for differences between man-made disasters and natural episodic events (such as fire, flood, and volcanic eruption). The magnitude and timing of natural events are integrally related and/or essential to many ecosystem processes. For example, annual flooding serves as a reset mechanism which maintains the long-term community structure of running water ecosystems[69] and the use of prescribed fire represents the return of a natural ecological factor to the environment.[70,71]

Concern for maximization or optimization of use of a particular resource has been tempered with more concern for long-term stability of that resource. Systems are dynamic, and man-induced changes frequently set in motion a response with undetermined and unforeseen consequences.[72] Long-term ecological records are essential for distinguishing natural oscillations from aberrant ecosystem behavior. This can be especially important in the management of fish and wildlife resources.[16] Among methods recently developed to analyze effects of man-induced or natural changes in the environment is that of intervention analysis,[73,74] which gives the probability that changes in mean level can be distinguished from natural data variability. The method is particularly sensitive to the way in which data are collected, and suggests (counterintuitively) that the post-intervention data record be substantially longer than the pre-intervention period. Long-term studies are rare and yet are often required for the recognition of thresholds beyond which habitat/ecosystem reclamation may become exceedingly difficult, if not impossible.

Recognition of Limits

The concept of threshold, or limit, denotes an absolute quantity as well as a level beyond which, for example, a given population or system property cannot be sustained. A prescribed area may have the potential (e.g., territory, food resource base, nesting or spawning habitat) to adequately support a limited number of animals. The equilibrium level of the population is generally referred to as "carrying capacity." The densities of some species (r-adapted) appears to be related more to the random variation in environmental factors than to long-term environmental requirements, whereas others (K-adapted) may be regulated by well-developed feedback mechanisms and have equilibrium population densities at or near the carrying capacity.[5] There is evidence that, once transgressed (e.g., by overgrazing), the carrying capacity of a particular region or ecosystem is reduced.[32]

Renewable and nonrenewable natural resources are currently exploited at rates and managed in ways that threaten man's survival.[75,76] America, from the earliest days of exploration, has been proclaimed the land of endless resources. To the pioneers, America was limitless—they wanted to make the most of labor, not the land.[77] The economic rationality of American democracy has led toward, among other things, waste of natural resources and environmental degradation.[77,78] The history of the forests and the prairies, and the fate of the bison bespeak the limited nature of this country's resources.[79] America has generally exploited resources of neighboring countries in lieu of fully recognizing her own limits.[80]

Post-industrialist attitudes, which view the resource base as variable depending on technology, have in many cases prevailed over neo-Malthusian attitudes, which view it as fixed. Among assumptions commonly made in assessing the status of a resource are: (1) that growth of both the human population and the economy of this country will continue, and (2) that there is an acceptable technological solution to environmental problems. These two notions result in continued action directed at symptoms of our predicament rather than at the causes. As stated by Bormann:

> Globally, we are locked into a positive feedback situation involving five principal factors that feed upon and reinforce each other: (1) All governments are committed to policies that emphasize maximal economic growth; (2) growth policies are sustained by ever-increasing consumption. This increase in consumption is brought about by: (3) rising populations of human beings and (4) rising per capita consumption in some countries; and, finally, (5) a rapidly growing technology is required to meet necessary and imagined demands by commitment to policies that will sustain economic growth.[81]

Events of the past decade, such as the oil crises of the 1970s and the views of earth from the Apollo missions, have provided generally an enhanced sense of the finiteness of this country's resources and of the error in other perceptions. An ever increasing proportion of the population now admits that there is an environmental crisis, that man is not in balance with the natural world, that there may be no acceptable technological solution.[76,82]

Legislation

The stated purpose of NEPA is:

> To declare a National Policy that will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological system and natural resources important to the nation. . . .

The decade of the 1970s, with commitment to environmental protection, bore witness to legislation passed in the late 1960s and 1970s focused on controlling pollution insults to air, water, and land. Quality criteria and standards and emissions standards were established to limit releases into the environment (e.g., Federal Water Pollution Control Act, Water Quality Act, Clean Air Act). More recent legislation (e.g., Toxic

Substances Control Act, Amendments to the Federal Insecticide, Fungicide and Rodenticide Act) has been in large part preventative in nature, indicating an aim at the sources, rather than the effects of environmental problems. In addition, laws have been generally more ecosystem directed; for example, the Fishery Conservation and Management Act has as its objective the management of interrelated stocks of fish as a unit or in close coordination rather than on a species-by-species basis. In addressing specific aspects of land (National Forest Management Act, Federal Land Policy and Management Act), air (Clean Air Act Amendments), and water (Clean Water Act Amendments) systems, environmental legislation enacted in the 1970s, perhaps more than any other set of documents, reflects concern for fish and wildlife protection through more stringent requirements for assessment and reasonable accuracy of prediction.

Preserving diversity in a world of rapidly shrinking land resources will require a prompt and universal response based on appropriate application of ecological knowledge and understanding.[83] Corporations have been granted legal rights; the step toward recognizing "legal rights of forests, oceans, rivers, and other so-called 'natural objects' in the environment—indeed of the natural environment and a whole"[84] is a small, but crucial one.[84,85]

EVALUATION OF EFFECTIVENESS OF ASSESSMENT AND PREDICTION

Several case studies have been chosen to represent accomplishments in environmental assessment and prediction during the 1970s. The shift in emphasis from single species protection to an ecosystem perspective, and from setting "standards" to initial prevention of potentially deleterious problems, however, must be taken into account in evaluation of the effectiveness of assessment and prediction of man-made impacts on fish and wildlife habitat. Technological advances in instrumentation and refinements in the sensitivity of analyses have made feasible much research that was previously impracticable.

Documentation of assessment and prediction, often in the form of environmental impact statements, does not include subsequent evaluation of corrective responses of local, state, or federal agencies, such as levying of fines or revocation of discharge permits. For that reason, it is difficult generally to evaluate the effect that assessment and prediction procedures have had on protection or restoration of fish and wildlife habitat.

Case Studies

Lake Washington represents a well-documented case study in which phosphorus enrichment was determined to be the major factor producing a decline in water quality; its removal was predicted to reverse the decline. This has been realized,[86] although not without unforeseen associated results.[87] The solution to the disturbance of this watershed was to export the problem to another system, Puget Sound. Similar export solutions are planned for the clean-up of Gull Lake, Michigan[88,89] and for Lake Tahoe.[90] Unfortunately, the question remains as to whether land use development beyond that which can be assimilated by a given basin should be allowed in that basin.

Changes in the Great Lakes, which accelerated in the 1970s, have resulted from general hydrologic alterations (e.g., canals, which, among other effects, allowed for invasions by marine species), increased point and nonpoint source effluents, intensive and selective fisheries, and species manipulations such as the introduction of salmonids.[91,92,93,94,95,96,97,98] Assessment that overfishing, pollution, and the marine lamprey (*Petromyzon marinus*) greatly reduced populations of larger predatory fishes and allowed for increases in the density of small forage fishes, including the invading alewife (*Alosa pseudoharengus*), led to the prediction that, given lamprey control and point source clean-up, introduced salmonids would flourish in the Great Lakes.[92,98] This prediction proved accurate in the short term, but failed to recognize potential overexploitation of food fishes by salmonids, or problems associated with bioaccumulation of dilute toxins in fish tissues.[99]

Bayou Texar (Pensacola, Florida) studies of community diversity and nutrient cycling by algae and bacteria led to recommendations which included run-off control and changes in basin morphometry. Implementation improved water quality, including the alleviation of fish kills.[100]

Diversity indices have been used frequently to describe the status of environmental quality[101,102,103] and have provided a basis for requiring clean-up of ecological systems.[104] Simplification of community structure under stress has been sufficiently documented[102] that such biological alterations in association with, for example, effluents are commonly taken as evidence for reduced environmental quality.[104]

Another case study representing accomplishments in environmental assessment and prediction during the 1970s is the ban of DDT from the U.S. market. This resulted from extensive data on the biological effects of the pesticide, such as reduced avian fecundity[105,106] and differential mortality of predators.[107]

Guidelines for reducing effects of large scale environmental change on ecosystems might be derived from some studies. For example, in integrated resource management of a watershed which is being logged, road-building, cutting, removal, and regrowth could be adjusted to reduce the severity of effects predicted from changes in assessed conditions.[108]

Relevance to Present and Future Considerations

Awareness that an ecosystem perspective is required to achieve effective management of a particular resource—e.g., for commercial harvest, recreation, aesthetics, or contaminant buffers—is believed to have resulted in enhanced ability to assess and predict accelerated or aberrant environmental change. Technological and methodological improvements in the tools of environmental assessment during the 1970s may have helped to increase the accuracy of prediction. As illustrated by problems in toxicity testing associated with defining suitable methods to alleviate the deficiencies of single species tests,[20] tools of assessment may not be adequate to the task at hand.

Environmental problems are proliferating and probably will continue to do so for the foreseeable future. They remain unpredictable—and persistent (e.g., how to store nuclear wastes?). New or aggravated problem areas of the 1970s include: effects of acid rain,[109,110] changes in atmospheric CO_2 from, for example, the burning of fossil fuels,[111] dredge spoils and landfills,[112,113,114] toxic substances,[20,115,116] thermal alterations from industrial[117] and power plant[118] cooling water and from nuclear production reactors,[119] entrainment and impingement,[120] pump-storage reservoirs and low-head hydroelectric power development,[57,121] and oil spills in coastal waters.[122] Adequate environmental management requires some semblance of understanding of natural environments, understanding which can only come from knowledge, training, concern, and experience. Improved methods and data, particularly of a long-term nature, are needed, but not without qualification. Although enormous quantities of data may be generated, environmental issues are frequently undecided, pending accumulation of more relevant data. Decisions must often be made before appropriate information can be collected. In addition, in some cases refined methods and analyses may not provide suitable objective information for evaluation. Uncertainty and qualitative judgments have become more prominent in environmental decisions, introducing delays which lead to increased regulatory costs and stresses between business and environmental concerns.[4]

Eipper[123] at the beginning of the decade stated "...because we are being forced to make increasingly critical decisions about ecosystems for which reliable predictive data are often lacking, we must, collectively, develop a framework of genuinely useful principles to guide our dealing with natural environments." One of these principles might be that of Prevention. The lack of suitable criteria and objective information for evaluation has been reiterated and attributed to weaknesses in ecological theory.[124] The demand for useless information needs to be diminished, and professional judgment, relied upon more fully.[125]

Professional judgments are required for interpretation of data and for decisions when appropriate data are lacking. This latter process is essential in areas (nonnumerical) in which the scientific method cannot be applied directly. Value judgments might best be made by a qualified authority who can assess effects, as determined by experts, using whatever standards might apply to the decision.[126] An example of areas not readily amenable to the rigors of science is the problem of landscape appraisal. Practical solutions lie between emphasis on perception by the consumer of scenic quality (Figure 4) and emphasis on quantitative or semi-quantitative evaluation of measurable components of landscape deemed representative of scenic quality.[127] Perception of landscapes varies with time, and within and between social and cultural groups. Scenic appreciation is so complex that quantification may be misleading.

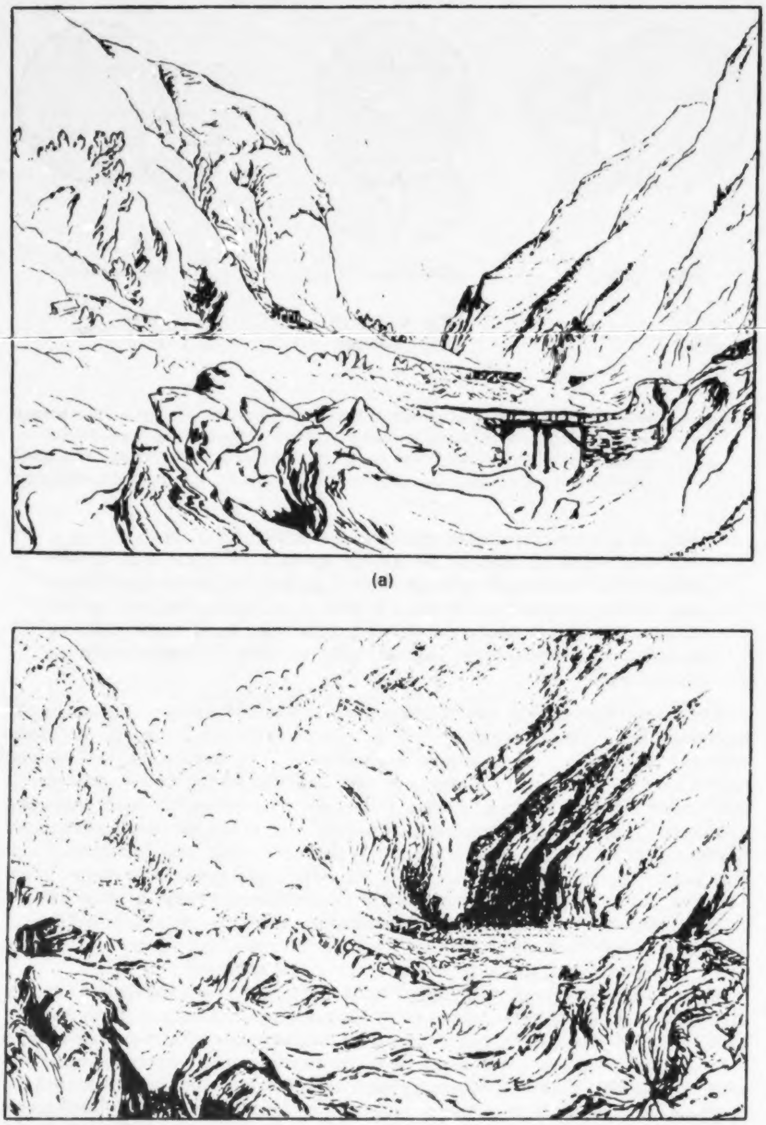
The ability of educational systems to provide training and experience that are adequate and learning that is appropriate for approaching the increased number of problems that demand synthetic views of reality needs to be examined. Vallentyne[128] suggests that students are ill-prepared, primarily because of the institution's focus on education of the individual "in isolation," and, therefore, advocates multi-disciplinary joint theses. Figure 5 provides a simple illustration of predominating areas of concern in ecological problems with which an applied ecologist might have to deal. Because of the continuing increase in systems that are man-made, knowledge that will allow the interfacing of management between man-made and natural systems is essential.[129]

As part of recognizing the extent of knowledge and understanding about increasingly complex issues, systems of values and beliefs need to be examined. For example, problems associated with dredge spoils, toxic wastes, and landfills serve particularly well to illustrate what Garrett Hardin[130] has termed the "tragedy of the commons." He develops the concept through use of the metaphor of an open pasture. Each herdsman reasons that for every animal he places in the pasture, his "positive utility" is +1, whereas his "negative utility" (should the pasture be overgrazed) is only a fraction of -1, because the effects are shared by all herdsmen. "Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. . . . Freedom in a commons brings ruin to all." Innumerable pollution and population problems, seen in the light of the "commons," make clear the need for fish and wildlife habitat protection. In the disposal of solid wastes, the commons is used as a dumping ground. The clean-up of Lake Washington was accomplished by diverting wastes to Puget Sound.[86]

CONCLUSIONS

The need for substantial change in ethics, values, and attitudes toward the environment has been voiced repeatedly.[76,131] Environmental insults resulting in alteration and/or destruction of fish and wildlife habitat are not "new";[132,133] the earth is far more populated now, and the rate of change has greatly accelerated. In 1770, America was overwhelmingly agricultural. Before rapid resource exploitation could occur, Indian land had to be distributed to the settlers, and new political, economic, social, and technological arrangements, developed.[77] What's "new" is that we now have the "energy and the technology to force the earth to our will rather than win her consent."[134] Enhanced environmental awareness and concern have certainly ameliorated some situations and set the stage for much needed work and change. Nonetheless essential, they alone are not enough.

Gunn,[135] in examining the question of extermination of species, argues that animal rights, usefulness, rarity and value, and wilderness as value in itself will not provide an answer to the person who cannot "see it." In a similar vein, Singer[136] reflects:



(a)

(b)

Figure 4. The Pass of Faido (a) as sketched by John Ruskin, and (b) as reproduced in etched outline by Ruskin from a drawing by Joseph Turner. "... astute observations of landform and geological structure, transformation of scale, and modification of location are skillfully used to convey an emotional portrait of the scene."[127] This analogy is taken from John Ruskin's *Modern Painters* (1843-60).

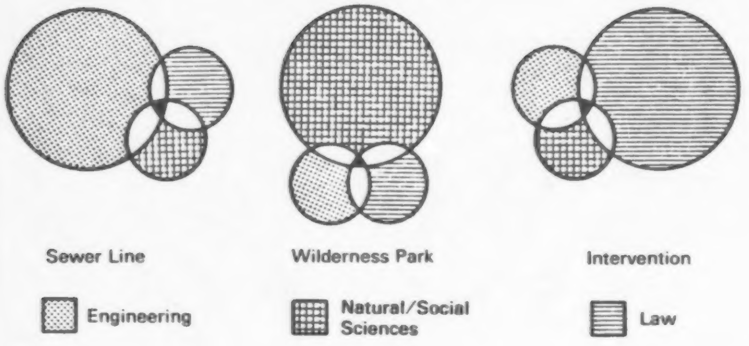


Figure 5. Predominating areas of concern in ecological problems with which an applied ecologist might have to deal include the above disciplines. One discipline may be more significant than others in a particular study. The overlapping area of concern is at the center of most environmental problems.[10]

> 'Why act morally?' cannot be given an answer that will provide everyone with overwhelming reasons for acting morally. Ethically indefensible behaviour is not always irrational. We will probably always need the sanctions of the law and social pressure to provide additional reasons against serious violations of ethical standards. On the other hand, those reflective enough. . .are most likely to appreciate reasons offered for taking an ethical point of view.

The problem of protecting and managing fish and wildlife resources is not totally economic, but rather involves ethical considerations. In this regard, the major emphasis by Larson on economic evaluation as the motivation for wetland regulation may not apply to all types of natural areas. Wetlands may be a special case—their inherent value, economic and other, may be sufficient to command public protection. Noneconomic bases for appreciation of habitat values are required to prevent continued loss of natural areas. If economic considerations are such that they can override the preservation of natural objects and species, the environment can never be given permanent protection.[137] Commitment to environmental value is crucial. Solutions will require total assessment of values and systems of beliefs, yet obligation toward the environment can be grounded in ecological principles in a way that is as sound as that available to any other ethical approach.[138]

Many issues have not been considered here, e.g., overpopulation, energy production and consumption, radiation, wilderness preservation, and man's environment (noise, transportation, and urban smog), but a number of threads run common throughout. For instance, the search for adequate representative means whereby to assess and predict effects of man-made impacts on fish and wildlife habitat needs to continue. At the same time, however, recognition of the deficiencies and limitations of analyses on which decisions are to be based may allow for thoughtful input from trained and experienced persons. If progress in knowledge and understanding of processes and systems is viewed in the light of vast areas of ignorance, minds may remain open and receptive to ideas and alternatives, active and fertile in searching for them. Many decisions involving a choice of either/or, with neither one being acceptable, require the courage to consider a more amenable set of alternatives. The deluge of environmental problems and the depth of imponderable numbers of issues necessitate that goals and objectives be carefully delimited, that focus on critical issues be sharpened. This requires a means of integrating, defining the resolution of, and prioritizing issues and concerns. The effectiveness with which any of the challenges encountered is dealt may depend on the ability to consolidate energy and expertise. Special groups might then be given responsibility for issues requiring urgent attention.

Ultimately neither the development of a global ethic nor decentralization appear likely given the present and projected human population. But there are many alternatives, some of which face the challenge of adapting advanced industrial societies to the realities of ecological constraints.[139,140,141,142] Reorganization of society may be energized by clearer vision of what life might be like under other conditions.[81] Leonard[134] speaks of the "occasional flash of illumination that's made us what we are by showing us we might become something better." Goals need to be verbalized, made conscious, and means by which to establish the priority of concerns they represent need to be determined and acted upon. This is an enormous undertaking, one which may well challenge basic beliefs and values—the ground was prepared during the seventies.

ACKNOWLEDGEMENTS

Oregon State University Agricultural Experimental Station Technical Paper No. 6213. We gratefully acknowledge the help of C. E. Warren in reviewing this manuscript, and of G. R. Marzolf, J. R. Barnes, and C. E. Cushing in reviewing an earlier draft. Figure 4 has been reproduced with permission from Oxford University Press.

REFERENCES

1. Sandhu, H. S. 1977. A definition of environmental research. Environ. Manage. 1:483.
2. Myers, N. 1976. An expanded approach to the problem of disappearing species. Science. 193:198-202.
3. Bragg, T. B., and A. K. Tatschl. 1977. Changes in flood-plain vegetation and land use along the Missouri River from 1826 to 1972. Environ. Manage. 1:343-348.
4. Edmunds, S. W. 1978. Trade-offs in assessing environmental impacts. Environ. Manage. 2:391-398.
5. Clapham, W. B., Jr. 1973. Natural Ecosystems. Macmillan. New York, N.Y. 248 pp.
6. MacArthur, R. H. 1955. Fluctuations of animal populations, and a measure of community stability. Ecology. 36:533-536.
7. Pimentel, D. 1961. Species diversity and insect population outbreaks. Ann. Entomol. Soc. Amer. 54:76-86.
8. Botkin, D. B. 1980. A grandfather clock down the staircase: stability and disturbance in natural ecosystems. pp. 1-10. *In* Forests: fresh perspectives from ecosystem analyses. R. H. Waring, ed. Oregon State Univ. Press. Corvallis, Ore.
9. May, R. M. 1976. Patterns in multi-species communities. pp. 142-162. *In* Theoretical ecology: principles and applications. R. M. May, ed. W. B. Saunders Co. Philadelphia, Penn. 317 pp.
10. De Santo, R. S. 1978. Concepts of Applied Ecology. Springer Verlag. New York, N.Y. 310 pp.
11. Heffernan, P. H., and R. Corwin, eds. 1975. Environmental Impact Assessment. Freeman, Cooper and Co. San Francisco, Calif. 277 pp.
12. O'Riordan, T., and R. D. Hey. 1976. Environmental Impact Assessment. Saxon House, D.C. Heath Ltd. Westmead, England. 232 pp.
13. Rosen, S. J. 1976. Manual for Environmental Impact Evaluation. Prentice-Hall, Inc. Englewood Cliffs, N.J. 192 pp.

14. Canter, L. W. 1977. Environmental Impact Assessment. McGraw-Hill Book Co. New York, N.Y. 331 pp.
15. Jain, R. K., L. V. Urban, and G. S. Stacey. 1977. Environmental Impact Analysis: A New Dimension in Decision Making. Van Nostrand Reinhold Co. New York, N.Y. 330 pp.
16. Botkin, D. B., ed. 1978. A pilot program for long-term observation and study of ecosystems in the United States. National Science Foundation, Washington, D.C. 44 pp.
17. Peet, R. K. 1974. The measurement of species diversity. Ann. Rev. Ecol. Syst. 5:285-307.
18. Ott, W. R. 1978. Environmental Indices: Theory and Practice. Ann Arbor Science Publ. Inc. Ann Arbor, Mich. 371 pp.
19. Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.
20. Environmental Studies Board. Committee to Review Methods for Ecotoxicology. 1981. Testing for Effects of Chemicals on Ecosystems. National Academy Press. Washington, D.C. 103 pp.
21. Canton, J. H., and W. Slooff. 1979. A proposal to classify compounds and to establish water quality criteria based on laboratory data. Ecotox. Environ. Safety. 3:126-132.
22. Vannote, R. L., and B. W. Sweeney. 1980. Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. Amer. Nat. 115:667-695.
23. Boling, R. H., E. D. Goodman, J. O. Zimmer, K. W. Cummins, R. C. Petersen, J. A. VanSickle, and S. R. Reice. 1975. Toward a model of detritus processing in a woodland stream. Ecology. 56:141-151.
24. Boling, R. H., R. C. Petersen, and K. W. Cummins. 1975. Ecosystem modeling for a small woodland stream. pp. 183-204. *In* Systems Analysis and Simulation in Ecology. B. C. Patten, ed. Vol. 3. Academic Press. New York. N.Y. 601 pp.
25. McIntire, C. D., and J. A. Colby. 1978. A hierarchical model of lotic ecosystems. Ecol. Monogr. 48:167-190.
26. Glass, G. V., P. D. Peckham, and J. R. Sanders. 1972. Consequences of failure to meet assumptions underlying the fixed effects analysis of variance and covariance. Rev. Educ. Res. 42:237-288.
27. Halfon, E., ed. 1979. Theoretical Systems Ecology, Advances and Case Studies. Academic Press. New York, N.Y. 516 pp.
28. Bailey, H. P. 1964. Toward a unified concept of the temperate climate. Geog. Rev. 54:516-545.
29. Franklin, J. F. 1977. The biosphere reserve program in the United States. Science. 195:262-267.
30. Warren, C. E. 1979. Toward classification and rationale for watershed management and stream protection. EPA-600/3-79-059. U.S. Environmental Protection Agency, Washington, D.C. 143 pp.
31. Harkins, J. P. 1976. Thou canst not stir a flower. Environ. Manage. 1:4-5.
32. Hardin, G. 1980. An ecolate view of the human predicament. pp. 49-71. *In* Global Resources: Perspectives and Alternatives. C. N. McRostie, ed. Univ. Park Press. Baltimore, Md.
33. Hynes, H. B. N. 1975. The stream and its valley. Verh. Int. Verein. Limnol. 19:1-15.
34. Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, and N. M. Johnson. 1977. Biogeochemistry of a forested ecosystem. Springer-Verlag. New York, N.Y. 146 pp.

35. Ellsaesser, H. W. 1971. Air pollution: our ecological alarm and blessing in disguise. E+S. 52:92-100.
36. Koenig, L. R. 1979. Effects of industrial effluents on local cloudiness and rainfall. Wat. Air Soil Poll. 12:47-69.
37. Dolan, R., P. J. Godfrey, and W. E. Odum. 1973. Man's impact on the Barrier Islands of North Carolina. Amer. Scientist. 61:152-162.
38. Thayer, G. W., D. A. Wolfe, and R. B. Williams. 1975. The impact of man on seagrass systems. Amer. Scientist. 63:288-296.
39. Hutchinson, G. E. 1970. The biosphere. Sci. Amer. 223:45-53.
40. Opler, P. A. 1980. A parade of passing species. Oregon Wildlife. Jan.:8-9.
41. Burns, J. W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Amer. Fish. Soc. 101:1-17.
42. Field, R., and P. J. Szeeley. 1974. Urban runoff and combined sewer overflow. J. Water Poll. Cont. Fed. 46:1209-1226.
43. Field, R., J. Curtis, and R. Bowden. 1976. Urban runoff and combined sewer overflow. J. Water Poll. Cont. Fed. 48:1191-1206.
44. Katz, M. 1969. The biological and ecological effects of acid mine drainage in Appalachia. Appalachia Regional Commission. Washington, D.C. 126 pp.
45. Carrithers, R., and F. Bulow. 1973. An ecological survey of the west fork of the Obey River, Tennessee with emphasis on the effects of acid mine drainage. J. Tenn. Acad. Sci. 48:65-72.
46. Hill, R. D., and E. C. Grim. 1975. Environmental factors in surface mine recovery. pp. 290-302. *In* Recovery of Damaged Ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, eds. Univ. Press Va. Charlottesville, Va.
47. Cummins, K. W., and G. L. Spengler. 1978. Stream ecosystems. Water Spectrum. 10:1-9.
48. Johnson, R. R., and J. F. McCormick. 1979. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Gen. Tech. Rept. WO-12. Forest Service, USDA. Washington, D.C. 410 pp.
49. Bormann, F. H., and G. E. Likens. 1970. The nutrient cycles of an ecosystem. Sci. Amer. 223:92-101.
50. McColl, J. G., and D. F. Grigal. 1977. Nutrient changes following a forest wildfire in Minnesota: effects in watersheds with differing soils. Oikos. 28:105-112.
51. Lewis, W. M., Jr. 1974. Effects of fire on nutrient movement in a South Carolina pine forest. Ecology. 55:1120-1127.
52. Lewis, W. M., Jr. 1975. Effects of forest fires on atmospheric loads of soluble nutrients. pp. 833-846. *In* Mineral cycling in southeastern ecosystems. (Conf. 740513). F. G. Howell, J. B. Gentry, and M. H. Smith, eds. Energy Research and Development Administration (DOE). Washington, D.C.
53. Holm, L. G., L. W. Weldon, and R. D. Blackburn. 1969. Aquatic weeds. Science. 166:699-709.
54. Winteringham, F. P. W. 1979. Agroecosystem-chemical interactions and trends. Ecotox. Environ. Safety. 3:220-235.
55. Soltero, R. A., J. C. Wright, and A. A. Horpestad. 1973. Effects of impoundment on the water quality of the Bighorn River. Wat. Res. 7:343-354.
56. Belt, C. B., Jr. 1975. The 1973 flood and man's constriction of the Mississippi River. Science. 189:681-684.
57. Baxter, R. M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst. 8:255-283.
58. Costa, J. E. 1978. The dilemma of flood control in the United States. Environ. Manage. 2:313-322.
59. Stanford, J. A., and J. V. Ward. 1979. Stream regulation in North America. pp. 215-236 *In* The Ecology of Regulated Streams. J. V. Ward and J. A. Stanford, eds. Plenum Press. New York, N.Y.

60. Omernik, J. M. 1976. The influence of land use on stream nutrient levels. EPA-600/3-76-014. U.S. Environmental Protection Agency, Corvallis Environ. Res. Lab. Corvallis, Ore. 105 pp.
61. Daniel, T. C., and R. R. Schneider. 1979. Nonpoint pollution: problem assessment and remedial measures; economic and planning considerations for designing control methods. pp. 829-852 *In* Planning the uses and management of land. ASA-CSSA-SSSA. Madison, Wisc.
62. Calamari, D., S. Galassi, and R. DaGasso. 1979. A system of tests for the assessment of toxic effects on aquatic life: an experimental preliminary approach. Ecotox. Environ. Safety. 3:75-89.
63. Ribeyre, F., A. Boudou, and A. Delarche. 1979. Interest of the experimental trophic chains as ecotoxicological models for the study of the ecosystem contaminations. Ecotox. Environ. Safety. 3:411-427.
64. White, R. J. 1973. Stream channel suitability for coldwater fish. Proc. Soil Cons. Soc. Amer. 28:61-79.
65. White, R. J. 1975. In-stream management for wild trout. pp. 48-59. *In* Proc. Wild Trout Manage. Symp. Yellowstone Natl. Park, Sept. 25-26, 1974. W. King, ed. Trout Unlimited, Inc. Denver, Colo.
66. Luedtke, R. J., M. A. Brusven, and F. J. Watts. 1976. Benthic insect community changes in relation to in-stream alterations of a sediment-polluted stream. Melanderia. 23:21-39.
67. Cairns, J., Jr. 1975. Critical species, including man, within the biosphere. Naturwissenschaften. 62:193-199.
68. Duff, D. A., and J. L. Cooper. 1976. Techniques for conducting stream habitat survey on national resource land. Bureau of Land Management, USDI. Tech. Note. 283:1-72.
69. Cummins, K. W. 1974. Structure and function of stream ecosystems. BioScience. 24:631-641.
70. Vogl, R. J. 1967. Controlled burning for wildlife in Wisconsin. Proc. Ann. Tall Timbers Fire Ecol. Conf. 6:47-96.
71. Vogl, R. J. 1975. Fire: a destructive menace or a natural process? pp. 261-289 *In* Recovery of Damaged Ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, eds. Univ. Press Va. Charlottesville, Va.
72. Simons, D. B. 1975. The geomorphic and hydraulic response of rivers. Trans. N. Amer. Wildl. Nat. Resour. Conf. 40:209-219.
73. Hipel, K. W., D. P. Lettenmaier, and A. I. McLeod. 1978. Assessment of environmental impacts, part 1: intervention analysis. Environ. Manage. 2:529-535.
74. Lettenmaier, D. P., K. W. Hipel, and A. I. McLeod. 1978. Assessment of environmental impacts, part 2: data collection. Environ. Manage. 2:537-554.
75. Borgstrom, G. 1971. Too Many: An Ecological Overview of Earth's Limitations. Collier-MacMillan Canada Ltd. Toronto, Canada. 400 pp.
76. Livingston, J. A. 1973. One Cosmic Instant: Man's Fleeting Supremacy. Dell Publ. Co., Inc. New York, N.Y. 243 pp.
77. Petulla, J. M. 1977. American Environmental History: The Exploitation and Conservation of Natural Resources. Boyd and Fraser Publ. Co. San Francisco, Calif. 399 pp.
78. Udall, S. L. 1963. The Quiet Crisis. Holt, Rinehart and Winston, Inc. New York, N.Y. 224 pp.
79. Matthiessen, P. 1959. Wildlife in America. Penguin Books. New York, N.Y. 304 pp.
80. Mesarovic, M., and E. Pestel. 1974. Mankind at the Turning Point. New American Library, Inc. New York, N.Y. 210 pp.
81. Bormann, F. H. 1972. Unlimited growth: growing, growing, gone? BioScience. 22:706-709.

82. Schumacher, E. F. 1977. A Guide for the Perplexed. Harper and Row Publ., Inc. New York, N.Y. 147 pp.
83. Terborgh, J. 1974. Preservation of natural diversity: the problem of extinction prone species. BioScience. 24:715-722.
84. Stone, C. D. 1974. *Should Trees Have Standing? Toward Legal Rights for Natural Objects.* Avon Books, The Hearst Corporation. New York, N.Y. 118 pp.
85. Vallentyne, J. R. 1978. Today is yesterday's tomorrow. Verh. Int. Verein. Limnol. 20:1-12.
86. Edmondson, W. T. 1972. Nutrients and phytoplankton in Lake Washington. pp. 172-193. *In* Limnol. Oceanogr. Spec. Symp. G. E. Likens, ed. 1:1-328.
87. Edmondson, W. T. 1979. Lake Washington and the predictability of limnological events. Arch. Hydrobiol. 13:234-241.
88. Moss, B. 1972. Studies on Gull Lake, Michigan. II. eutrophication - evidence and prognosis. Freshwat. Biol. 2:309-320.
89. Tague, D. F., and G. H. Lauff, eds. 1973. Gull Lake: past, present, future. Kalamazoo Nature Center. 26 pp.
90. Goldman, C. R. 1981. Lake Tahoe: two decades of changes in a nitrogen deficient oligotrophic lake. Verh. Int. Verein. Limnol. 21:in press.
91. Beeton, A. M. 1965. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceanogr. 10:240-254.
92. Smith, S. H. 1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Bd. Canada. 25:667-693.
93. Smith, S. H. 1972. Factors of ecologic succession in oligotrophic fish of the Laurentian Great Lakes. J. Fish. Res. Bd. Canada. 29:717-730.
94. Berst, A. H., and G. R. Spangler. 1972. Lake Huron: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Bd. Canada. 29:877-887.
95. Christie, W. J. 1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Bd. Canada. 29:913-929.
96. Hartman, W. L. 1972. Lake Erie: effects of exploitation, environmental changes and new species on the fishery resources. J. Fish. Res. Bd. Canada. 29:899-912.
97. Lawrie, A. H., and J. F. Rahrer. 1972. Lake Superior: effects of exploitation, and introductions on the salmonid community. J. Fish. Res. Bd. Canada. 29:765-776.
98. Wells, L., and A. L. McLain. 1972. Lake Michigan: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Bd. Canada. 29:889-898.
99. Frank, R., H. E. Braun, M. Holdrinet, D. P. Dodge, and S. J. Nepszy. 1978. Residues of organochlorine insecticides and polychlorinated biphenyls in fish from Lakes St. Clair and Erie, Canada—1968-76. Pest. Monitor J. 12:69-80.
100. Moshiri, G. A., N. G. Aumen, and W. G. Crumpton. 1980. Reversal of the eutrophication process: a case study. *In* Proc. Int. Symp. Nutrient Enrichment Estuaries. A. J. McErlean, ed. Humana Press. Clifton, N.J. (in press).
101. Chandler, J. R. 1970. A biological approach to water quality management. Water Pollut. Contr. 4:415-422.
102. Cairns, J., Jr., K. L. Dickson, and G. R. Lanza. 1973. Rapid biological monitoring system for determining aquatic community structure in receiving systems. pp. 148-163. *In* Biological methods for the assessment of water quality. Amer. Soc. Test. and Materials. Philadelphia, Pa.
103. Cooke, S. E. 1976. Quest for an index of community structure sensitive to water pollution. Environ. Poll. 11:269-288.

104. Cairns, J., Jr., K. L. Dickson, and E. E. Herricks. 1975. Recovery and Restoration of Damaged Ecosystems. Univ. Press Va., Charlottesville, Va. 531 pp.

105. Henny, C. J. 1972. An analysis of the population dynamics of selected avian species with special reference to changes during the modern pesticide era. Wildl. Res. Rept. 1. Fish and Wildlife Service, USDI. Washington, D.C. 42 pp.

106. Haegele, M. A., and R. H. Hudson, 1973. DDE effects on reproduction of ring doves. Environ. Poll. 4:53-57.

107. Henny, C. J. 1977. Birds of prey, DDT, and tussock moths in the Pacific Northwest. Trans. North Amer. Wildl. Res. Conf. 42:397-411.

108. Narver, D. W., and T. W. Chamberlin. 1976. Carnation Creek—an experiment towards integrated resource management. Circular 104. Pac. Biol. Sta. Nanaimo, B.C., Canada. 20 pp.

109. Likens, G. E. 1975. Acid precipitation: our understanding of the phenomenon. pp. 45-75. *In* Acid precipitation. Proceedings of a conference on emerging environmental problems. EPA-902/9-75-001. U.S. Environmental Protection Agency, Region II, New York, N.Y.

110. Dochinger, L. S., and T. A. Seliga, eds. 1976. Proceedings of the first international symposium on acid precipitation and the forest ecosystem, May 1975, Columbus, Ohio. Northeastern Forest Exp. Sta. Forest Service, USDA. Upper Darby, Pa. 1074 pp.

111. Delcourt, H. R., and W. F. Harris. 1980. Carbon budget of the southeastern U.S. biota: analysis of historical change in trend from source to sink. Science. 210:321-323.

112. O'Neal, G., and J. Sceva. 1971. The effects of dredging on water quality in the Northwest. Off. Wat. Prog., Region X, U.S. Environmental Protection Agency. Seattle, Wash. 158 pp.

113. Anonymous. 1977. Proceedings of the conference on geotechnical practice for disposal of solid waste materials, June 13-15, 1977. American Society of Chemical Engineers. New York, N.Y. 885 pp.

114. Massoglia, M. F., ed. Dredging in estuaries: a guide for review of environmental impact statements. Research Triangle Inst. Research Triangle Park, N.C. 271 pp.

115. Anonymous. 1978. Toxic materials in the aquatic environment. Water Resour. Res. Inst., Oregon State Univ. Corvallis, Ore. 165 pp.

116. Butler, G. C. 1978. Principles of Ecotoxicology—Scope 12. John Wiley and Sons. New York, N.Y. 350 pp.

117. Clark, J. R. 1969. Thermal pollution and aquatic life. Sci. Amer. 220:18-27.

118. King, J. R., and E. R. Mancini. 1975. Effects of power plant cooling water entrainment on the drifting macroinvertebrates of the Wabash River (Indiana). pp. 368-372. *In* Proc. Second Thermal Ecology Symp. Augusta, Ga.

119. Gibbons, J. W., and R. R. Sharitz. 1974. Thermal alteration of aquatic ecosystems. Amer. Scientist. 62:660-670.

120. Jensen, L. D., ed. 1978. Fourth national workshop on entrainment and impingement. EA Communications, Div. Ecol. Analysts. Melville, N.Y. 424 pp.

121. Ward, J. V., and J. A. Stanford. 1979. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. pp. 35-55. *In* The ecology of regulated streams. J. A. Stanford and J. V. Ward, eds. Plenum Press. New York, N.Y.

122. Krebs, C. T., and K. A. Burns. 1977. Long-term effects of an oil spill on populations of the salt-marsh crab, *Uca pugnax*. Science. 197:484-487.

123. Eipper, A. W. 1970. Pollution problems, resource policy, and the scientist. Science. 169:11-15.

124. Kerr, S. R., and W. P. Vass. 1973. Pesticide residues in aquatic invertebrates. pp. 134-180. *In* Environmental pollution by pesticides. C. A. Edwards, ed. Plenum Press. New York, N.Y.
125. Ghiselin, J. 1978. Environmental reports for the Nuclear Regulatory Commission: guidelines thwart sound ecological design. Environ. Manage. 2:99-103.
126. Ghiselin, J. 1978. Perils of the orderly mind: cost-benefit analysis and other logical pitfalls. Environ. Manage. 2:295-300.
127. Cooke, R. U., and J. C. Doornkamp. 1974. Geomorphology in Environmental Management. Clarendon Press. Oxford, England. 413 pp.
128. Vallentyne, J. R. 1974. Limnology and education in the next decade. J. Fish. Res. Bd. Canada. 31:513-519.
129. Barrett, G. W., G. M. Van Dyne, and E. P. Odum. 1974. Stress ecology. BioScience. 26:192-194.
130. Hardin, G. 1968. The tragedy of the commons. Science. 162:1243-1248.
131. Sale, K. 1980. Human Scale. Coward, McCann and Geoghegan. New York, N.Y. 558 pp.
132. Hynes, H. B. N. 1960. The Biology of Polluted Waters. Univ. Toronto Press. Toronto, Canada. 202 pp.
133. Warren, C. E. 1971. Biology and Water Pollution Control. W. B. Saunders Co. Toronto, Canada. 343 pp.
134. Leonard, J. W. 1975. Ethics and realities. pp. 44-58. *In* Environmental quality and society. R. A. Tybout, ed. Ohio State Univ. Press. Columbus, Ohio.
135. Gunn, A. S. 1980. Why should we care about rare species? Environ. Ethics. 2:17-37.
136. Singer, P. 1979. Practical Ethics. Cambridge Univ. Press. New York, N.Y. 237 pp.
137. Hargrove, E. C. 1979. The historical foundations of American environmental attitudes. Environ. Ethics. 1:209-240.
138. Marietta, D. E., Jr. 1979. The interrelationship of ecological science and environmental ethics. Environ. Ethics. 1:195-207.
139. Odum, H. T. 1971. Environment, Power, and Society. John Wiley and Sons, Inc. New York, N.Y. 331 pp.
140. Odum, H. T. 1976. Energy Basis for Man and Nature. McGraw-Hill. New York, N.Y. 297 pp.
141. Edmunds, S. W. 1978. Alternative U.S. Futures: A Policy Analysis of Individual Choices in a Political Economy. Goodyear Publ. Co., Inc. Santa Monica, Calif. 217 pp.
142. Schnaiberg, A. 1980. The Environment: From Surplus to Scarcity. Oxford Univ. Press. New York, N.Y. 464 pp.

SCIENCE FOR PUBLIC POLICY: HIGHLIGHTS OF ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT

C. S. Holling

It all started with GIRLS. That was the acronym chosen for the Gulf Island Recreational Land Simulation study. GIRLS was an exercise to explore ways of bridging gaps between disciplines, and between subject-matter experts and policy designers. It was the first step in a sequence that has since led to the concepts, methods and procedures of adaptive environmental assessment and management (AEAM).

The essential purpose of AEAM is to provide a flexible, adaptive approach to environmental planning, assessment, and management. Its methods draw upon a variety of modeling techniques to capture the essential biophysical and economic interactions, on policy analytic techniques to generate alternative policies, and on decision techniques to evaluate policy consequences. Its procedures emphasize a sequence of interactive workshops whose purpose is to combine the strengths of the expert, the manager and policy maker so that relevant knowledge is focused on policy questions which lead to adaptive decision making. The approach has been described in detail[1] and in summary form[2] elsewhere. Here I shall concentrate on the dilemmas, complexities, and issues that arise in the development and application of such an approach.

This approach dates back to 1968 when it seemed opportune to capitalize on two trends. At that time, we observed, "first, there was a growing realization that a new class of resource and environmental problems was appearing, as exponential demand stretched the resilience of resource and environmental systems.

Second, with the development of computers and modeling techniques, new approaches and methods had been developed to handle complex systems with many variables. For the first time, therefore, it seemed possible to design new research and policy strategies for those situations having large numbers of interacting components.

In order to capitalize on this historical junction, however, it was essential to recognize that the history of the resource sciences had been moving very much in the opposite direction. Each of the disciplines—resource economics, ecology, geophysics, agriculture, fisheries, wildlife biology—had been developing overlapping but often independent methods and concepts. In addition, related forces had led to a growing separation between institutions, so that gaps developed in the logical flow of activities from basic to applied research, to design and pilot studies, and to policy formulation and implementation. Wherever we looked, therefore, it seemed that there were gaps between methods, between disciplines, between institutions and between constituencies. The gaps in this sequence of activities, shown in Figure 1,

---

The Author: Professor Holling is on leave from the Institute of Resource Ecology, University of British Columbia, Vancouver, Canada, to serve as Director of the International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria. His present research interest is in the physiology of surprise!

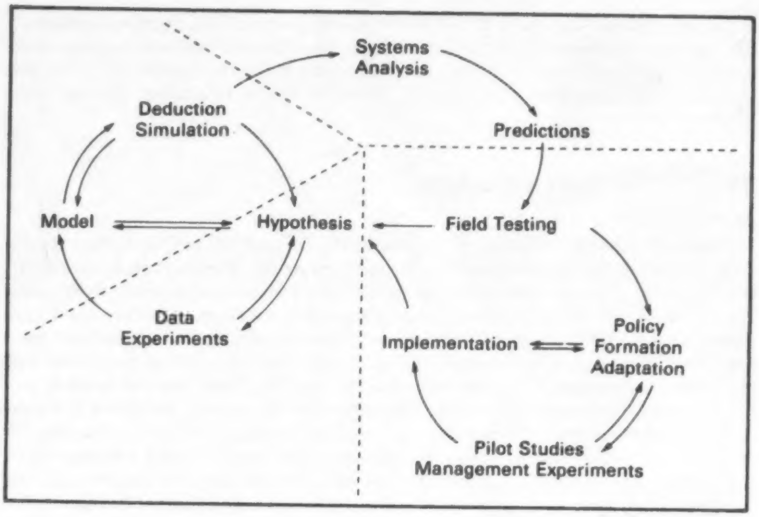


Figure 1. Sequence of activities required in analyzing resource systems and devising policies for management. The gaps inhibiting this progression are indicated by the broken lines.

seemed sufficiently embedded in the history of resource science to demand a carefully organized series of steps that could progressively bridge the gaps."[3]

Most of those gaps were bridged, at least to some significant degree. But others have appeared. It is the purpose of this paper to review the highlights and to identify the new problems and gaps that have emerged. In short: what we learned and where we are stumbling.

WHAT WE LEARNED

The paragraphs in quotes and Figure 1, which were composed in 1968, still seem to be an adequate description of the status at that time. But our experience since then suggests three critical additions. First, the gaps in the sequence of activities are obviously matched by gaps between people—between expert, manager, decision advisor, decisionmaker, and citizen. Hence the challenge was not simply to better understand the interrelated behavior of fish or fowl or economies, or to develop wonderful methods of modeling and policy analysis. It was more to develop an understanding of people—hence the communication methods and workshop procedures of AEAM where the strengths of disciplinary experts, policy analysts, managers and decisionmakers are blended.

The second addition is the two-way interaction between policy formation and implementation, emphasizing the unpredictable nature of policy design and implementation and the need to evaluate and adapt to the inevitable unexpecteds. And, finally, as indicated in the figure, several words needed to be added for emphasis: *deduction* added to simulation to emphasize that there are a variety of different kinds of models (not just simulation models), each with different strengths; *adaptation* added to policy formation to emphasize, again, the adaptive nature of renewable resource assessment and management; *management experimentation* added to pilot studies to emphasize the active role of management design in probing and exploring the unknown.

Those additions lie at the heart of the adaptive approach. They represent aspects of the conceptual lessons learned. But concepts need to be matched with technique and technique has to emerge from practice. The highlights of the version of techniques that we evolved emerged from practical examples that, in retrospect, fell into three phases.

Phase 1: What GIRLS Taught Us

Problem Entry

Any problem can be entered at various levels, from global to micro. And yet the final results are largely determined by the entry point. More often than not, the entry point is dictated by one's own past experience. Hence, in a recent workshop exploring the consequences of alternative routes to transport oil from Alaska to the Puget Sound area, a wild fowl specialist argued that measures of wild fowl populations were the prime integrator of information concerning the state of environmental health of the marine ecosystem. A fisheries biologist, on the other hand, saw the world as one of catch/effort statistics and stock-recruitment relations in which productivity would be impacted by oil spills. Both these views can be accommodated in the same analysis because they imply similar scales in space and time. Both require designation of alternative tanker routes, representation of spill probabilities, development of submodels of oil movement, and estimates of population and animal movement by location and time of year. But a senior policy advisor of government argued that a larger scale analysis of energy supply and demand could well indicate that any transport of oil by tanker over new routes was unlikely because of likely changes in supply and demand. That represents a much larger geographical scale of analysis over a longer period of time, but the end result could well alert the wildlife and fisheries biologists to issues and questions emerging in a radically different direction from their original inclination. Rather than simply reacting to proposed tanker routes that might never appear, they could, as well, anticipate developments and be part of their design.

It is not that one scale of problem definition is correct and one wrong. In this example both are useful—the first in preparation for formal hearings concerning four specific proposals; the second in anticipation of the next round of issues just over the horizon. The point is that the scale of problem definition used should be an explicit decision based on needs, not on one's own area of expertise.

Problems are defined not only by the scale in space and time but also by the choice of the processes most responsible for generating and responding to change. GIRLS is a case in point. The Gulf Islands, off the coast of British Columbia, have rare living resources on land and sea that have been progressively impacted by expanding demands for recreation and development. The first entry point, however, was not biological—it was economic and social, for it was the forces of population growth, land acquisition and development that were the engines of change. This provided the opportunity, then, for biologists and others to evaluate alternative futures in terms of their primary interest and to explore alternative social and economic policies that could better protect or enhance those interests. That can set the stage to pinpoint second-order analyses where their special expertise can come into play. Subsequent to the GIRLS exercise, for example, the AEAM approach was used with fisheries biologists, economists, managers and policy people to develop radically new perceptions of the impact of sport fishing on salmon, and to develop new policies that are now being put into practice.

The prime lessons: one's own interest cannot blindly dictate the point of entry into a problem; whatever the point of entry, there are contributions to be made to one's own interest; whatever the point of entry, it is useful to explore the consequences on larger and smaller scales.

Do Not Start with Objectives—End with Them

Objectives of individuals or groups would seem to provide a logical way to start an analysis. A representative of a wildlife agency, for instance, might express his objectives in terms of protection (of wildlife) or battle (with the developer). At times one objective can dominate the other so that in the drive to "get" the developer, for example, long-term objectives relating to wildlife can be unconsciously compromised—winning a battle and losing the war.

That problem of conflicting and hidden objectives within and between organizations presents the first problem. We encountered that early in the GIRLS project and found that the effort to define alternative objectives at the beginning was divisive and unproductive. We resolved the impasse by insisting that any early discussion of objectives be limited to defining both policy actions and evaluation indicators. Actions are those management or regulatory levers that can be applied using rules that define a policy. For example, a simple fisheries policy might be to control fishing using actions such as limiting the size, bag, season or area in accordance to a rule that maintains a fixed number of spawning fish. Indicators are those quantities that in various combinations can define an objective. Indicators such as population density, productivity, income and catch can then be used to evaluate the ability of a policy to achieve different objectives such as maximizing sustained yield or economic return, minimizing income variability, or enhancing social equity. People can fruitfully define sets of actions and evaluation indicators knowing that at the end of the analysis alternative policies to meet their objectives can thus be explored.

The second problem in starting with a firm definition of objectives arises from the assumption that people know their objectives. But all our experience, and indeed that of pollsters of political elections, indicate that objectives emerge as a result of dialogue and growing understanding. The analyses and procedures should have that as their end-point, not their beginning. We have found this point of view to be particularly difficult for people from agencies with single missions to accept. And most difficult for those far from the scene of the problem. After all, if you are in headquarters, what else can you do to control your local personnel than to insist they define their objectives and stick to them? The result is the articulation either of fervent dogma or of counterproductive trivia.

The prime lessons: the identification of actions and indicators at the first gives policy direction to an analysis and limits the area of conflict; starting with objectives generates irrelevant conflict and minimizes learning: objectives are as much a part of the research and learning experience as is the development of understanding and policies.

A Model is Not an Analysis

The GIRLS model and other similar simulation models represent an effort to develop a kind of laboratory world that can be used to integrate existing knowledge and identify gaps, to respond to questions, and to adjudicate conflict. There has been enough written in various fields that I will not dwell on their strengths (integration of parts to generate systems behavior, incorporation of non-linearities, and many variables) or weaknesses (danger of becoming too large, too detailed, too complex and unrelated to the questions). But a model is only effective if it is embedded in a larger process of analysis—problem identification, modeling, policy design and evaluation, and policy decision and implementation. We learned from GIRLS that a simulation model can be a powerful device to blend the knowledge of different disciplines, to make invisible assumptions visible, and to provide an environment to ask questions. That can lead to priorities for filling key knowledge gaps and to the exploration of the systems effects of actions and policies. But that only emerges if it integrates with the other parts of the process. Hence we learned quickly that GIRLS had to be transparent, capable of easy modification as questions emerged, and able to produce graphical information of different levels of detail and generality. Later studies that brought in a wider range of actors and constituencies only confirmed that need.

Prime lesson: simulation models can be a powerful tool in the overall process of analysis, but only if the communication interfaces with the other parts of the process are fostered.

Methods of Analysis are Not Enough

We have conducted analyses that use only a limited array of quantitative methods, either because information or understanding was sparse and qualitative or because the problem was technically straightforward. But I cannot imagine an AEAM project that was not structured around one or a sequence of workshops. For at its heart, the problem of linking disciplinary knowledge, policy design and evaluation is a problem of linking people—experts, managers, policy designers, decisionmakers, and constituencies.

The major barrier to AEAM is the scarcity of staff who have rigorous disciplinary experience and analytic and modeling skills combined with experience in dealing sensitively and constructively with people. But perhaps that combination of talents lies latent in more people than traditions would indicate. Certainly that is our experience in training individuals and teams from the U.S. Fish and Wildlife Service, Canada Department of the Environment, and within our university's graduate school. I present a graduate course in modeling methods and workshop procedures, for example, in which typically four or five individuals out of a class of 15 to 20 emerge with that combination of skills. They must start with a strong disciplinary background and analytic skills. What is needed is a forum to tune, apply and expand those skills and to match them with people skills.

Those procedures were first developed in the GIRLS workshop,[4] and refined, expanded and modified in subsequent ones.[5,6] They dealt with ways to capitalize on and, at times, generate rhythms of frustration and advance, how to organize and not organize, how to deal with conflicts of principle, dogma and detail, when and how to be interdisciplinary, when and how to concentrate on disciplinary knowledge, and how to enrich and focus methods of communication and interaction. These procedures have been used in Austria, Canada, South America, the United Kingdom, and the United States. Although the basic features remain the same, different cultures and nationalities require adaptation of the details. What remains universal is the roles that appear during a workshop: the Peerless Leader who, with astonishing commitment and perception, takes on leadership roles for the greater good; the Utopian, who dreams the impossible dream and yet provides visions that can be filtered to separate imaginative ideas from fantasy; the Blunt Scot, a rare individual whose bluntness and sincerity of purpose transcends the mischievous irresponsibility that most of us succumb to occasionally. And finally there is Snively Whiplash, who clearly detests the whole effort, wishes to destroy it, and for some reason stays on throughout. But he is invaluable, for he can provide a focus of hostility that can crystallize a group spirit that can then be turned to more constructive purpose. The greatest danger we have encountered is that Snively can become a convert, and if sufficiently narrow can initiate subsequent activites that subvert the essential need to be adaptive and flexible.

The prime lesson: people, procedures, communication, and orchestration have to be pursued as a creative, carefully designed activity that matches knowledge and methods.

Phase II. Small is Beautiful Versus Big is Necessary

That experience set the stage for experiments in organizing the AEAM approach. Carl Walters undertook a set of experiments designed to explore how small and focused the organization could be and how rapidly the first stages could be implemented. Mike Goldberg and I dared to organize an effort that was both interdisciplinary and interinstitutional, with the aim of providing an open access planning and information system for the lower mainland of British Columbia. That was IIPS, the Inter-Institutional Policy Simulation Study—not as entertaining an acronym as GIRLS, perhaps suggesting that we were taking ourselves too seriously. Both experiments experienced failures, as experiments should. Failures provide the opportunity for learning. But the first set was highly forgiving of error because the experiments were small in scale, were replicated, and had a stated experimental purpose. In contrast, the second was large in scale, was of necessity unreplicated, and had an operational purpose. Those are precisely the ingredients that are unforgiving of error.

That experience led to a particular kind of organization that was neither the traditional interdisciplinary team nor the "contracting-out" device. It led also to a refinement of procedures and methods that accelerated the process. The following specific lessons were learned.

Big is Not Beautiful

The experiments showed that a large, centralized interdisciplinary team effort was unnecessary. The IIPS project showed, moreover, that such efforts were excessively costly in organizational, financial and emotional overhead. That project was organized with initial formal commitment of several departments of the city, a regional planning department, and the university. Fear of the unknown and fear of unexpected political consequences was, however, clearly present at the beginning. Nevertheless, the first year proceeded admirably through a series of workshops, the conceptualization of the problem, the identification of component parts and initial analysis and modeling of those parts and of the interconnections between them. The regional planning department in particular made public the benefit it received. The fundamental pitfalls that emerged were typical of many of the early large-scale efforts of systems analysis, and these have been well reviewed elsewhere.[7,8,9] There was inevitable drifting of the component analysis from the initial policy purposes to more diffuse scientific or philosophical purposes. There was the endless debate that process was everything versus the product was everything, when both process and product have to be inextricably linked.

But the basic lesson is that large-scale interdisciplinary projects are unnecessarily costly and require excessive organization and control.

Moderately Small is Necessary

At the other end of the scale, small efforts involving experts of single disciplines can be equally ineffective, even when the purpose is narrow. A number of workshops were held focusing on aquatic ecosystem studies sponsored by the International Biological Program. Those were largely descriptive field programs and we experienced little success in introducing the notion, for example, of dynamic causation and systems behavior, or of the use of models to direct and be directed by data collection and analysis. The parochial aspect of single disciplines too often reinforces dogma, buries hidden assumptions deeper and smothers the analysis in irrelevant detail. Counteracting forces are needed to emphasize the need to respond to specific questions, not to all questions, the need to identify gaps in understanding or data, and the need to assess the significance of those gaps.

Mixes of disciplines can help provide the balance as the narrowness of one discipline encounters that of another. Moreover, the significance of interactions between parts of a system is forced into the open. But we found the optimum balance was provided by a mix including experts from several relevant disciplines, resource managers and policy people. The former keep the latter two honest. The latter keep the former relevant.

The prime lesson is that single disciplines can be blindly parochial and incestuous and that a blend of expert, manager, and policy people can lead to a balanced interplay of strengths. There is a much enhanced chance that specific questions of importance will be addressed, that priorities for key information needs can be established and that fruitful and unexpected policies can be identified.

Organization Has to be Adaptive Too

Smallness can allow for regulated flexibility. Even problems of large scale and purpose can be structured as a set of smaller functions that can be interrelated with the minimum of organizational overhead. The organization we evolved by trial and error involves four groups:

The Project Team. The project team is the client who has typically been charged by one institution to perform an assessment or to design and evaluate alternative policies concerning a resource and environmental problem. That problem in the past has been as narrow as management of a specific fisheries or wildlife population or as broad as a regional analysis of a major hydro-electric, or other development that has broad social, economic, environmental and resource consequences. In one instance, the problem was continental—albeit involving the sparsely occupied continent of Antarctica.[9] There is no reason why the problem could not be global (e.g. climatic change resulting from CO_2 accumulation) except for the need to identify alternatives to the nonexistent global decision maker.

Workshop Staff. This is the group of four to six analysts who jointly have backgrounds in a number of different resource disciplines, are familiar with a spectrum of analytic modeling and policy techniques, and have the talents and experience to facilitate and guide groups of people in workshop and post-workshop settings.

The Core Planning Group. This is made up of the leader of the Project Team, perhaps one or two of his senior staff, and the workshop staff. Their responsibility is to plan and set the sequence of activities, to identify institutional opportunities and problems, and to identify key participants in various institutions—experts, managers and policy people. The Program Leader and Workshop Staff lead and guide the workshop(s), acting as a policy analytic staff for the Participants.

The Participants. The participants are the experts, managers and decision people, typically from a number of institutions, who have key roles to play in technical or decision aspects of the problem. They are the ones invited to the first workshop. Their talents and experience are orchestrated to produce a first-cut model of the problem that is used to assign priorities for information and data needs, model development and policy analysis.

The sequence of activities starts with a scoping session of one or two days involving only the Core Planning Group. The problem is explored in some detail in order to develop an initial bounding of the problem—actions, indicators, variables, spatial extent and resolution, time horizon and resolution. That is done only to the degree necessary to identify key participants and information requirements for the first workshop. Responsibilities are assigned for collation and organization of existing information, for selection and invitation of participants and for organization of the workshop itself.

The first workshop follows within two months, and over five days operates in a rhythm that moves from establishing the policy framework (actions and indicators), to interdisciplinary identification of variables, space and time and the interconnections between them, to development of submodels by disciplinary groups, and finally to exploration of policy and information questions. The result is a set of priorities for information, for modeling, analysis and policy design, together with responsibilities to address those needs.

That typically is followed by a two- to three-month period of independent work leading to a second workshop with the same people to produce a refined analysis, model and policies, and priorities for subsequent steps. Again, periods of independent work follow, paced and ordered by other workshops. Some of these are designed only for technical people in order to subject the work to criticism and to expose it to a larger technical audience who often have significant advisory roles in policy making. Later workshops focus on a larger community of managers, decision-makers, and citizens. Throughout, the rules are to make everything as transparent as possible, to provide an interactive environment, and to modify the analysis, models and evaluation as new questions and suggestions emerge.

The prime lessons: a small organization with the core tightly organized and the participants more loosely integrated can address not only simple but highly complex resource and environmental problems; a great multiplication effect occurs through the network of participants that reduces the central budget, accelerates communication, and provides an early warning of problems. Sanity, innovation, and learning are encouraged by the rhythm of intense short periods of interdisciplinary and policy analysis, interspersed with independent consolidation; the scheduling and focus of each workshop sets the deadlines and pace. And finally, every effort must be made to provide opportunities for self-discovery by all actors.

Connecting the Parts of a Model

Submodels are the parts of the full model. They are chosen to include variables which interact tightly, in a complex manner and at similar scales of space and time. The goal is to divide the problem into submodels such that relatively little information needs to be communicated between them. Those interconnections are absolutely key, for from them come many of the unexpected policy effects as social, economic, resource, and biophysical aspects combined. They generate those surprises, crises and opportunities that challenge so much of resource and environmental management.

In every workshop some of the experts push to represent their submodel in exquisite detail. They are understandably motivated by scientific rather than policy interest. But that leads to a level of complexity and detail that typically prevents linkage of submodels. Carl Walters resolved that with the innovation of the "Looking-Outward Matrix." The notion is deceptively simple. Do not let the expert tell you what information he can provide. He cannot be expected to know what other experts or policy makers need. Rather ask him what *he* needs from other experts' submodels. That leads to a matrix that identifies the variables and units that each submodel needs from others. Hence, the interconnections between the parts are identified from the start. Reading the table one way identifies the inputs that a submodel will receive. Reading the other way identifies the outputs that others require. In addition, each sub-group knows the actions that need to be incorporated and the indicators that have to be generated. The definition of inputs and actions and of outputs and indicators goes a remarkable distance in defining the contents and scale of each submodel. And it gives an overview of the structure of the system that, in some workshops, has been all that was required to better order and focus the research and policy effort.

Prime lesson: Many interdisciplinary and "contracting-out" modes of analysis defeat the policy purpose because the component parts of the studies can never be interconnected. The solution is not to ask the expert what he can do for you; ask him what he needs from others. The results are used to structure the constraints imposed on each component analysis so that they respond to the policy needs at a relevant level of detail.

Phase III. The Proof of the Pudding is in the Eating

By 1974 we had developed effective ways to bridge gaps between disciplines, methods and concepts, between analysis and policy design and between expert, manager and policy maker. Equally important, we had learned how *not* to bridge the gaps between institutions. Hence, we entered a new stage of implementation. We wanted problems that contained immediate issues of major social, economic and environmental concern, within complex institutional settings. We wished to move the full range from analysis to decision. Four major projects evolved:

Forest/Pest Management. The pulp and paper industry and employment in New Brunswick, Canada had been maintained since the 1950s by an extensive insecticide spraying program. The target was the spruce budworm which periodically has destroyed most of the mature balsam of that province. The spraying program had reduced tree mortality but at a price: incipient outbreak conditions covering larger and larger areas, escalating costs, greater dependency on continued spraying, public opposition, and no easy or perceived options. Some 20 government agencies have some say in the matter and two key ones were at loggerheads—a federal agency responsible for research and a provincial agency responsible for management—with all the entwined personalities, grievances and territorial defense which that implies.[10]

Salmon Management and Enhancement. Salmon populations on the west coast of Canada are 50% of their original levels with the likelihood of collapses of major stocks only now being detected by public interests. Management of commercial and sports fishing faces the classic problems of mixed stocks, technology outstripping regulation, conflicting pressures from commercial, sports and environmental interests, divisions between research and operational agencies, and provincial, federal and international conflicts. A major investment into salmon enhancement facilities will produce more fish, with the potential of triggering the same sequence seen for spruce budworm management. Increase of enhanced populations will lead to increased harvest of all stocks, so that the less productive natural stocks will be driven to collapse. The industry can be left precariously dependent on a few enhanced stocks that are vulnerable to collapse.[11]

Regional Development in an Alpine Region. Obergurgl is a village in the Austrian Alps. Its population of 300 is inundated each year by some 40,000 tourists. Prior to 1950 the village lived a precarious and isolated existence based on high alpine farming—so precarious that from 1830 to 1850, the community decided to ban marriages. One hundred years later came the explosions of tourism, and now 70 hotels with associated ski lifts and hiking trails dominate the village. The problems are a microcosm of global and regional problems—erosion and environmental degradation that threaten the new economic base, fear of too much demand, and of too little demand, rising expectations and conflict—between haves and have-nots (hoteliers and farmers), young and old. In 1975 the conflicts were deep and growing.

Problems of a Single Mission Agency. Agencies with the single mission of protecting and managing fish and wildlife often lack extensive legislative and administrative powers. As a consequence, their personnel often view themselves as beleaguered defenders of cherished values that are under continual and successful attack. Continual erosion and destruction of those values seems inevitable. And externally, they are often viewed as a reactive and reactionary organization containing competing fiefdoms bound by traditions whose defense becomes more important than does resource stewardship. In order to explore alternative ways for such agencies to deal with their special mission in a world of many missions and needs, a number of specific problems were chosen typifying such issues for the U.S. Fish and Wildlife Service. They included problems of water resource allocation both in the Truckee-Carson system of Nevada and in California, of animal damage control in the Pacific Northwest, and of acid rain impacts on fish. Each involved fish and wildlife interests, each intersected directly with other missions of other agencies, and each encountered conflicts with different constituencies.

Those four projects thus share the classic set of problems faced by most examples of resource and environmental management. But they also shared one other critical ingredient that determined their choice. Each had an individual within the system who became a critical partner in the endeavor. They were the professional implementors, and the university group were the amateurs. This group of four wise men were so central that they shared with us the responsibilities for both the strengths and weaknesses of developments. They and others described the triumphs and frustrations of implementation in a policy seminar of the International Institute for Applied Systems Analysis (IIASA) held in June 1979.[12] And further events have transpired since then:

Budworm. The federal research agency remains little changed but the operational agency (the Department of Natural Resources, New Brunswick) has changed its program of inventory and wood supply analysis and has instituted a policy and planning division covering all aspects of forest management under the direction of a new Assistant Deputy Minister—our very own wise man, Gordon Baskerville.

Salmon. The Salmonid Enhancement Program was a new, semi-autonomous entity committed from the start to the adaptive philosophy and approach. Policy, planning and operations are hence interwoven with those notions. The salmon management program was part of an existing line department that initiated a change in the management approach when, for other reasons, the strategic and most of the tactical level staff were lost in an organizational change in 1978. Now, however, a new group has begun to implement new fishing regulations triggered, in part, by AEAM.

Obergurgl. The grand success story is Obergurgl. A critical town meeting was held in 1974 in which citizens and officials debated the issues with an interactive computer model as the mediator of questions and the core group as the facilitators. Farmer, hoteliers and scientists now claim that the model, analysis and interactive meeting turned growing polarization and conflict into collaboration. There has been no hotel construction since, and hoteliers have established funds to subsidize farming activity and further modeling and analysis to cope with future surprises. They argue that quite apart from specific decisions that followed, the most significant and profound result was that farmers now feel an honored and integral part of the village's future.

U.S. Fish and Wildlife Service (USFWS). The effort to encourage change focused on the training of a workshop staff within the service. That was accomplished by having them do it—run workshops, perform analyses, interact and orchestrate. If you are going to learn to swim you have to jump in the water. The projects chosen were hence experimental—in part, the participants suffered from the learning experience; in part they benefited from it. Significant contributions were made to the Truckee-Carson River Quality Assessment Project in direct collaboration with the U.S. Geological Survey (USGS) and to the San Joaquin/Sacramento Rivers analysis in collaboration with the FWS California Water Policy Center. The group is now completely able to conduct workshops and post-workshop activities. Satellite groups have emerged elsewhere. Whereas once our phone was frequently ringing with requests for assistance, now we have to phone to discover their continuing triumphs and frustrations.

Only when the pudding is eaten are the ingredients tested. Hence these final lessons are central to changes sought for in the management and protection of renewable resources. A senior administrator and policy advisor in government summarized his problem in this way: "Scientists keep telling me what a bunch of dolts bureaucrats are, and bureaucrats keep telling me what a bunch of nurds scientists are." And methodologists damn and are damned by both. How do we select and combine knowledge, methods and institutions for a policy purpose?

The critical problems and lessons are as follows:

1. *Science.*
   The workshop procedures and the qualitative and quantitative methods provide an effective way for the scientists and experts involved to develop a

coherent expression of their understanding and coherent advice to the manager and administrator. Alternative policies emerge that are qualitatively different from those previously devised and an effective range of comprehensible choice is provided for decision. But we discovered as well that the quality of the science itself was radically improved. This new discovery emerged because implementation demands that which is simple, clear and relevant. Above all, science seeks for understanding. And simplicity is the hallmark of understanding.

2. *Methods.*

Much of the theory and methodological developments took place in collaboration with outstanding analysts at IIASA—with Dantzig of optimization fame, Raiffa of decision theory, and Koopmans of economics. The revolution in our thinking concerning concepts and methods was triggered by them and is discussed in detail elsewhere.[13]

Optimization and techniques of decision and utility theory are modestly useful so long as they are not believed. The number of variables and nonlinearities encountered in resource problems exceed the capacity of existing techniques. If simplifying assumptions are made, they do provide interesting starting points to direct endeavor. But those very simplifications can arouse justifiable contempt in the mind of the decisionmaker as he exposes their gross impracticality.

There should not be one model. There should be several, since all models are lies—at best, partial representations of reality. Each provides a different perceptual window. Truth lies at the intersection of conflicting lies. Such models cannot be validated, they can only be invalidated, just as hypotheses can only be disproved. The key therefore is to establish the limits of credibility of the model by putting it at risk. And that can be done in both public and private settings. As a consequence, the analyst must put himself at risk as well, in order to establish his own limits of credibility for his publics.

3. *Institutions.*

For all its challenges, fun, and value, implementation is agony. For every day of analysis, implementation can require six days of communication, mutual learning, trial-and-error, and interaction at all decision and staff levels. Moreover it requires as much creativity and professionalism as does analysis and requires considerably more wisdom and patience.

The effectiveness of implementation is critically dependent on a "wise man" who is an integral part of the institutional environment. His position need not be one of obvious authority, but he must have influence and the respect (even if grudging) of other institutional actors. But those actors are organisms like any other, and as any good biologist must recognize, have well-developed survival responses. Many of these, legitimately or illegitimately, frustrate innovation and change. Some of the frustration comes from experts, managers or decisionmakers who simply are motivated to continue doing familiar things irrespective of their need or value—to seem to be busy and useful. How many data collection programs and field surveys, for example, are dominated by the desire to measure that which is easily measurable and not that which is important? Some frustrations come from territorial defense. Progress of the budworm study, for example, was profoundly slowed by senior management of the Canadian federal research agency who demanded that sufficient recognition be given to their "contribution" by setting their terms for involvement of the provincial agency. That stopped progress toward implementation for nearly two years.[10] Similarly, agencies attempt to protect negotiating positions. Senior management of a key agency of the State of Nevada refused to participate or have his staff participate in a workshop for fear of revealing data and positions at a time of looming legal conflict involving the Truckee-Carson water problem. Finally, middle management in government and industry often represent a bulge of incompetence that frustrates change within an organization, however much desired above and below. In the words of the Vice-President of a major international mining corporation, "there is a good reason why many middle managers never become senior ones."

Above all, implementation requires patience. It requires time for ideas to gestate, for inter-personal and inter-institutional adjustments to occur. It requires time for key unlocking events to occur—a crisis, an election, a public hearing. Some can be planned, most occur as surprises. At one point the budworm study seemed, at best, to have only changed data collection programs, albeit significantly. All efforts to institute policy change seemed to be frustrated at the eleventh hour. In despair, Baskerville wrote an explicit critique of Federal, Provincial and our own activities for the IIASA policy seminar.[10] There were three responses: first, it is not true; second, it is true but we cannot do things differently; third, Baskerville, how would you like a job as Assistant Deputy Minister.

WHERE ARE WE STUMBLING

Life is ever delightfully uncertain and ambiguous: the act of bridging gaps has led to new gaps and to new problems. At the moment we can hardly define whether they are important or transient, so they are presented here as potential problems only. Perhaps they will disappear.

Some Models Have Predicted Too Well

All work on GIRLS stopped in 1970 and, moreover, the model was initialized with data from 1900. Yet the model has tracked, surprisingly well, changes in selling prices, rates of development and rates of environmental decline since 1970. Similarly, the budworm model, in a more qualitative way, accurately predicted radically different behaviors in different regions of North America. That is surprising because we always argued that simulation models were lies, whose quantitative predictions could not be trusted and whose usefulness was in giving insight and mediating constructive dialogue. We could argue that the reason for this high predictive power came because we insisted on a process structure that relied on well-tested and carefully generalized presentations of those processes. But we are simply not sure. The reason why this is a problem is precisely that. One cannot, *a priori*, identify the limits of predictive power or robustness, no matter how much effort goes into invalidation. It was much easier when we could automatically disbelieve the results!

Being Adaptive is Essential, But---

There is certainly no doubt that one cannot predict everything, anticipate all surprises. That is why we argue for an adaptive emphasis that allows probing, experimentation, learning and change. But we encounter two problems. The first is that we are living in an unforgiving world that penalizes error, gambling, and hence learning. The very word adaptive has been attacked by elements of the USFWS and the Bureau of Land Management. Some who feel beleaguered in their defense of the environment believe in an all-or-none world, and that an adaptive sequence will lead to a *fait accompli* for the developer. Give the developer a pilot study and he will take a project!

The second problem with an excessive emphasis on an adaptive approach is that for certain developments the actual costs of experiment error can truly be too large for society to bear; chemicals that trigger cancer decades later, or nuclear power plants. We can keep trying to develop new designs that are more forgiving of error, but we are stuck with many that demand some kind of predictive screening devices.

But what are the rules for stopping the search for bad effects? Search hard enough and practically anything has deleterious consequences. What is the balance between prediction, regulation and adaptation? Swing one way and it is too dangerous, swing the other and it smothers innovation.

The Embrace of Ignorance

In many situations we have discovered what seems to be an explicit wish to be ignorant:

- "If I remain ignorant I can't be held culpable." That seems to motivate expensive surveys and the fear of evaluation.
- "If everyone, including me, remains ignorant I have the chance of seeming to be decisive." That seems to be the regulator's dilemma. It has led to the forcing of tertiary water treatment requirements, ostensibly to protect an endangered fish species when the real threat probably relates to spawning and homing questions. But no one wants to find out because it is easier to force the policy.
- "If I keep others ignorant, then life is easier and I will win." That is a common syndrome for reasons of negotiation, fear of losing control, and protection of power. Every one of our projects has encountered that problem to some degree.
- "If I remain ignorant of others' goals, approaches and insights, I can retain my purity in defense of those values that I cherish." Parochialism and adherence to cherished beliefs are major causes of miscalculation.

Public Involvement

The adaptive approach in principle would seem to be tailored for the public. At the minimum it makes assumptions visible, forces unanticipated questions, leads to design of alternatives, and defines the reasons for leaving things out. And it certainly worked having direct involvement of the people of Obergurgl. But the problem is size. Workshops (as distinct from information sessions) can contain only about 25 participants. Perhaps the route is to involve those publics who wish to contribute (from each according to his ability, to each according to his *work*?). That could lead to management experiments, monitoring and response in which public groups were an integral part of the design and operation. Hardly an easy thing to do in the unforgiving society where, with some reason, some publics have lost their trust. But if it is not attempted as a creative and balanced effort of integration, environmental and resource management will be faced with ever-increasing surprises and failures.

ACKNOWLEDGEMENTS

This work would have been barren and academic but for those wise men from key agencies who knew what implementation means and who became partners in specific endeavors—particularly Gordon Baskerville, Al Wood, and Allan Hirsch. Carl Walters was as much the innovator and developer of the whole process as I, and we are indebted to a remarkable set of colleagues and coauthors from our Institute, IIASA, and other collaborating institutions.

REFERENCES

1. Holling, C. S., ed. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons. Chichester, England. 377 pp.
2. Anon. 1979. Expect the unexpected. Executive Report 1. International Institute for Applied Systems Analysis. A-2361. Laxenburg, Austria.
3. Holling, C. S. 1968. A resource science program. Internal Document. Univ. of British Columbia. Vancouver, B.C., Canada.
4. Holling, C. S., and A. D. Chambers. 1973. Resource science: the nurture of an infant. Bioscience. 23(1):13-20.

5. Walters, C. J. 1974. An interdisciplinary approach to development of watershed simulation models. Technol. Forecast. Soc. Change. 6:299-323.

6. Holling, C. S., ed. 1978. Orchestrating the assessment. pp. 47-56. *In* Adaptive Environmental Assessment and Management. John Wiley and Sons. Chichester, England.

7. Brewer, G. D. 1975. An analyst's view of the uses and abuses of modeling for decision making. Paper P-5395. Rand Corp.

8. Mar, B. W. 1974. Problems encountered in multidisciplinary resources and environmental simulation models development. J. Environ. Manage. 2:83-100.

9. Majone, G., and E. S. Quade. 1980. Pitfalls of Analysis. John Wiley and Sons. Chichester, England. 213 pp.

10. Holdgate, M. W., and J. Tinker. 1979. Oil and other minerals in the Antarctic: the environmental implications of possible mineral exploration or exploitation in Antarctica. Scientific Committee for Antarctic Research. Scott Polar Research Institute. (Lensfield Road) Cambridge, U.K.

11. Baskerville, G. 1979. Implementation of adaptive approaches in Provincial and Federal forestry agencies. pp.21-67. *In* Adaptive environmental assessment and management. Current progress and prospects for the approach. Summary Report. 1st Policy Seminar. CP-79-9. Anon. 1979. International Institute for Applied Systems Analysis. A-2361. Laxenburg, Austria.

12. Larkin, P. A. 1979. Maybe you can't get there from here: a foreshortened history of research in relation to management of Pacific salmon. J. Fish. Res. Bd. Canada 36(1):98-106.

13. Anon. 1979. Adaptive environmental assessment and management. Current progress and prospects for the approach. Summary Report. 1st Policy Seminar. CP-79-9. International Institute for Applied Systems Analysis. A-2361. Laxenberg, Austria.

14. Clark, W. C., D. D. Jones, and C. S. Holling. 1979. Lessons for ecological policy design: a case study of ecosystem management. Ecol. Modeling. 7:1-53.

INDIRECT CAUSALITY IN ECOSYSTEMS: ITS SIGNIFICANCE FOR ENVIRONMENTAL PROTECTION

Bernard C. Patten

During the environmental decade of the 1970s this nation undertook to redress the abuses of former generations and restore our polluted waters, bad air, deteriorating cities and abused landscapes to states more conducive to "productive and enjoyable harmony between man and his environment." On the first day of the decade the National Environmental Policy Act was enacted into law, and the country was launched on a crusade for environmental protection. Legislation was passed which established air quality standards, pollutant, and hazard safe levels for the work place, improved waste management, and control of water pollution and toxic substances. In the 1970s, words like Santa Barbara, Love Canal and Three Mile Island, Kepone, DDT, PCBs and "nuke" became etched on the national consciousness as part of the vocabulary of struggle. And indeed, it was a struggle to reduce the hazards of a neglected environment to human health and well-being, to correct our wasteful habits, and to reclaim, develop and conserve our precious natural resources.

Great and obvious progress was made, particularly in areas of glaring imbalances and abuses. Still more progress needs to be achieved on the tractable problems. But as the decade of the 1980s proceeds, we can expect to see an increasing shift of emphasis to more difficult problems requiring more refined methodologies. Environmental protection will tend to grade over into environmental management in which competing uses will vie more cleverly and subtly for ever more limited resources. "Environment" will not remain a fuzzy generality, but will have to be comprehended and dealt with for what it is—what ecologists call "ecosystems": the total collection of living things and associated abiotica within an area.

Conventional environmental protection is not particularly ecosystem oriented. The concept does occasionally enter practical concerns as an abstraction from academia, but by and large it is not operational. Endangered species are now protected only because they are rare, not necessarily important, in blithe disregard of the lesson from paleontology that species were made to go extinct. Standards for toxicant levels are based on laboratory bioassays; never mind that ecology abundantly demonstrates that the organism of the laboratory is not the same, functionally or behaviorally, as its counterpart in nature.

The present unholistic paradigm, with its origins in laboratory experimentation, will not disappear in the 1980s, but it will be challenged and its foundations will begin to be eroded in two ways. First, tough problems requiring a more sophisticated view

---

The Author: Bernard C. Patten is Professor of Zoology, University of Georgia, Athens, and President of Ecology Simulations, Inc. His primary interests are at the ecosystem level of organization. He presently is conducting two ecosystem research programs, one in the Okefenokee Swamp (NSF) and the other on the continental shelf of the Gulf of Mexico (NOAA). He is also involved in development of a mathematical system theory of environment.

and methodology will not yield to conventional approaches. What can be achieved in environmental protection will level off well beneath what is needed, and the stresses and strains for revision will begin to set in. Second, the organism-environment complex as an inseparable natural unit will gradually ascend in academic circles as appreciation for the mutual interdependency of everything in a region becomes ever more forcefully demonstrated by ecologists. The "systems approach" will then begin to be seen as the only way to achieve necessary refinements enabling precision and deftness in the attack on environmental problems.

Once system wholeness becomes widely perceived as the underlying reason for ineffective solutions, a commitment to the development of an ecosystem based science of environmental protection will develop. It is doubtful that this will happen before the late 1980s. Here I would like to try to accelerate this evolution by demonstrating in simple, but no uncertain terms, the central defect of any approach based on direct, single factor causality as we tend to find it in the laboratory.

ECOLOGICAL NETWORKS

Ecology itself has been traditionally immune or resistant to the idea of system. The accepted concept of environment (*see* Notes, a) is one which specifically excludes indirect causes, and the ecological niche (Notes, b) is a direct factor niche only. Theories of limiting factors, tolerance, adaptation and natural selection are all constructs that relate strictly to variables of direct experience by the organism. This allows a quasi-rationality of the organism, or its population or even genome, to enter the system of explanation in the form of "strategies" for adaptation, optimal fitness or survival (Notes, c). The facts may be that in most ecosystems such strategies probably could not be effective because the direct causes to which they are supposedly responsive constitute only a small portion of the total influence which reaches an organism from a given source. If true, explanations would have to be revised to include higher order influences.

The conventional ecological focus on direct causes is anti-system, an outgrowth of a deep philosophical separation of the organism from its environment (Notes, d). Ecologists cannot yet admit co-implication and co-evolution of organism and environment unitary wholes because the methodology required to treat such units is not yet in place. However, food web elaboration by radiotracers, the on-again, off-again romance with microcosms, and ecosystem modeling and systems analysis all represent movement in the holistic direction. Some years ago, I participated in a demonstration that as new biota were added to laboratory microcosms the interactive networks changed both structurally and kinetically.[14] These changes were manifested in coefficients for radiocesium transfers within the experimental systems, coefficients not of system level phenomena, but representing direct input-output processes (feeding and excretion) of individual organisms. The message was: change the network, change the organism. An organism and the system environing it were closely linked as a functional unit, and both were altered by a change in either.

Causal networks in nature are diverse and complicated so that the "network variable" in ecology is in fact a variable to be contended with. It can be incorporated into formal treatment of the propagation of cause in ecosystems.[15] It can be the basis for a system theory of environment,[16] or niche,[7,8] in which indirect factors are integral. And, it can be encompassed by an organism-environment whole in which mutual consistency, co-adaptation and co-evolution of all the parts together are inherent properties.[17] This paper will demonstrate how indirect causes can significantly exceed direct causality in static networks by use of a partial ecosystem model.

Development of a rich interactive biotic structure in an ecosystem is conditioned by the physical environment. In severe environments, such as near the poles, in extreme deserts, or hypersaline bodies of water, ecosystem development is foreshortened. The species list is short, food chains and webs are simple, and controls are more physical than biological. In benign environments of temperate and tropical regions, where median conditions prevail, biotic development is manifold. Species diversity increases, food webs become interminably intermingled, and elaborate biotic interactions (biochemical, intraspecific, symbiotic and biocoenotic) become controlling. It is in these latter circumstances that the network variable becomes predominantly important.

MARINE ECOSYSTEM MODEL

In Figure 1, the whole ecosystem model consists of four submodels: Plankton, Nekton, Benthos, and Organic Complex (Notes, e). Plankton and Benthos are aggregated as compartments 8 and 9, and the environment (outside the broken border) consists of pelagic and benthic detritus of the Organic Complex submodel which flows across the boundary as inputs and outputs. The Nekton compartments are guild-like, being based on the input and output carbon environments inhabited by virtue of feeding and excretion habits which reflect migration, spawning and development patterns of different basic life history ontogenies.

FIRST ORDER (DIRECT) CAUSES AND EFFECTS

The northern continental shelf of the Gulf of Mexico is biogeographically subtropical in a moderate environment, so that rich biological development is

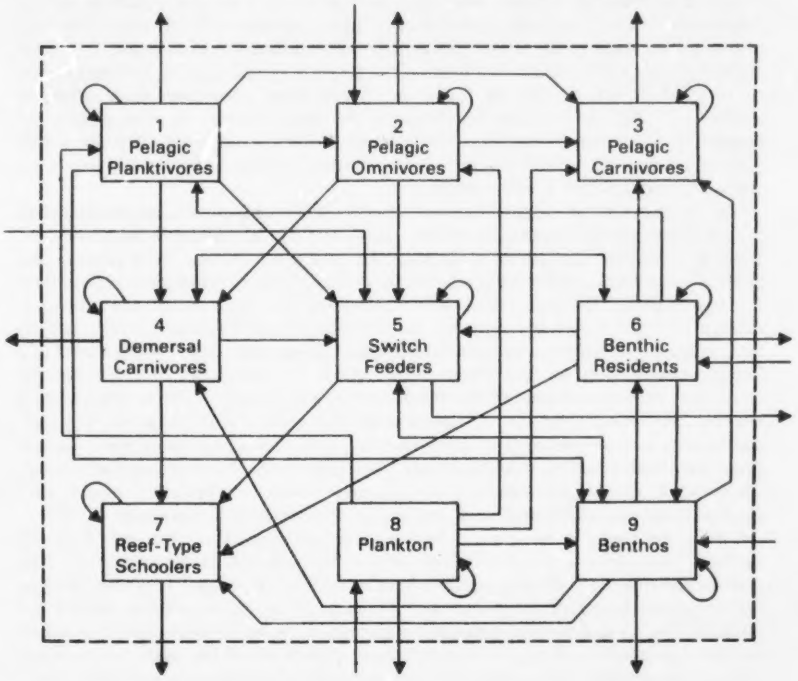


Figure 1. Northern Gulf of Mexico regional ecosystem Nekton submodel (compartments 1-7), with coupling to Plankton (8), Benthos (9) and Organic Complex (environment) submodels. Arrows represent carbon flows. Inputs from environment are due to detritivory, and outputs are by excretion. Intrasystem flows represent feedings.

expected of its ecosystems. This is reflected in the Figure 1 carbon flow network. Of 72 possible interactions between the compartments, not counting the self interactions of each compartment, 27 are realized for 38% connectivity. The upper matrix of Table 1 is an adjacency matrix representing the interactions shown in Figure 1. "Adjacency" because each entry of "1" represents a direct carbon exchange from a column compartment to the corresponding row compartment over a path of length 1.

These carbon flows are quantified in the lower matrix of Table 1, where each entry represents the daily fraction of carbon in each column compartment transferred by each row compartment (Notes, f). The columns in this matrix sum to 1 over the entire ecosystem model, and hence are ≤ 1 (in principle, < 1 actually) within the Figure 1 subsystem. Thus, the entries quantify daily carbon exchanges on a scale between 0 and 1, and will here be taken to exemplify influences of the column compartments on the row compartments (Notes, g). The largest values are intracompartmental, along the principal diagonal, reflecting strong predator-prey interactions between the species within each compartment and also the tendency of carbon not to be transferred to other compartments in a given day. As strong as these diagonal values are, and as relatively small as the intercompartmental interactions appear in comparison (0.021 is the largest nondiagonal value), it will be shown that indirect influences are predominant.

Table 1. Adjacency Matrices for the Figure 1 Model.
***Upper:* Presence (1) or Absence (0) of Direct Feeding Flow from Column to Corresponding Row Compartments.**
***Lower:* Direct Influence, as Daily Fractions of Column Compartments Contributed as Food Over Length 1 Paths Identified in the Upper Matrix.**

						from				
		1	2	3	4	5	6	7	8	9
	1	1	0	0	0	0	1	0	1	0
	2	1	1	0	0	0	0	0	1	0
	3	1	1	1	0	0	1	0	1	1
	4	1	1	0	1	0	1	0	0	0
to	5	1	1	0	1	1	1	0	0	1
	6	0	0	0	1	0	1	0	0	1
	7	0	0	0	1	1	1	1	0	1
	8	0	0	0	0	0	0	0	1	0
	9	1	0	0	0	1	1	0	1	1

						from				
		1	2	3	4	5	6	7	8	9
	1	.900	0	0	0	0	.003	0	.040	0
	2	.029	.900	0	0	0	0	0	.009	0
	3	.012	.021	.930	0	0	.003	0	.003	.001
	4	.002	.001	0	.950	0	.007	0	0	0
to	5	.005	.004	0	.012	.950	.003	0	0	.002
	6	0	0	0	.009	0	.971	0	0	.013
	7	0	0	0	.004	.003	.002	.950	0	.002
	8	0	0	0	0	0	0	0	.825	0
	9	.009	0	0	0	.011	.006	0	.008	.979

HIGHER ORDER (INDIRECT) CAUSES AND EFFECTS

Second Order

If each Table 1 matrix is multiplied by itself (Notes, h), the product matrices represent, respectively, the number of paths of length 2 and the daily fractional carbon flow summed over these paths from each column compartment to each corresponding row compartment. These matrices appear as the upper and middle matrices of Table 2. The upper one shows there are more paths of length 2 in the

Table 2. Matrices for Indirect Paths of Length 2 in the Figure 1 Model.
Upper: **Number of Length 2 Paths from Column to Row Compartments.**
Middle: **Indirect Influence, as Daily Fractions of Carbon in Column Compartments, Transferred to Row Compartments Over Length 2 Paths.**
Lower: **Total Influence, as Summed Daily Carbon Fractions of Column Compartments, Transferred to Row Compartments Over Paths of Lengths 1 Through 2.**

		from								
		1	2	3	4	5	6	7	8	9
	1	1	0	0	1	0	2	0	2	1
	2	2	1	0	0	0	1	0	3	0
	3	4	2	1	1	1	4	0	5	3
	4	4	2	0	2	1	4	0	3	3
to	5	5	3	0	3	2	5	0	3	4
	6	2	1	0	2	1	3	0	1	3
	7	3	2	0	4	3	5	1	1	5
	8	0	0	0	0	0	0	0	1	0
	9	3	1	0	2	2	4	0	3	3

		from								
		1	2	3	4	5	6	7	8	9
	1	.810	0	0	>0	0	.006	0	.069	>0
	2	.053	.810	0	0	0	>0	0	.017	0
	3	.023	.038	.865	>0	>0	.006	0	.006	.001
	4	.003	.003	0	.903	>0	.013	0	>0	.001
to	5	.010	.008	0	.022	.903	.006	0	>0	.005
	6	>0	>0	0	.017	>0	.944	0	>0	.024
	7	>0	>0	0	.008	.005	.004	.902	>0	.004
	8	0	0	0	0	0	0	0	.681	0
	9	.016	>0	0	>0	.021	.011	0	.014	.959

		from								
		1	2	3	4	5	6	7	8	9
	1	1.710	0	0	>0	0	.010	0	.109	>0
	2	.082	1.710	0	0	0	>0	0	.026	0
	3	.035	.059	1.795	>0	>0	.009	0	.008	.002
	4	.005	.004	0	1.853	>0	.020	0	>0	.001
to	5	.015	.012	0	.034	1.853	.010	0	>0	.007
	6	>6	>0	0	.026	>0	1.915	0	>0	.037
	7	>0	>0	0	.013	.008	.006	1.853	>0	.006
	8	0	0	0	0	0	0	0	1.506	0
	9	9	>0	0	>0	.033	.017	0	.022	1.938

Figure 1 system than of length 1 (Table 1). For example, there are two length 2 paths from the demersal carnivore compartment (4) back to itself, and there are four such paths from benthic residents (6) to benthos (9). These are (Figure 1) 4→4→4 and 4→6→4 in the first instance, and 6→1→9, 6→5→9, 6→6→9 and 6→9→9 in the second.

The middle matrix of Table 2 shows the cumulative strengths of the length 2 influence paths in terms of daily fractional carbon flows (values a''_{ij} denoted "> 0" range $0 < a''_{ij} < 0.0005$). The value from compartment 4 back to itself is 0.903, which is 95% of the self influence over the length 1 path (0.950, Table 1). The value from compartment 6 to 9 (Table 2) is 0.011, which is greater than the direct path value of 0.006. The total effect over length 1 and 2 paths is obtained by summing their individual effects (Table 2, lower matrix). These values can now exceed 1 because each parallel path between two compartments has a value ≤ 1, and the individual path values are summed.

The total effect of compartment 4 on itself over length 1 and 2 paths is 1.853 (51% direct and 49% indirect), and for compartment 6 on 9 the value is 0.017 (35% direct and 65% indirect). All the diagonal entries in Table 2 are smaller than corresponding values in Table 1, so the direct paths are more significant in this category. The nondiagonal values are all larger, however, so in every intercompartmental interaction the length 2 paths are more important than those of length 1.

Third Order

The same holds for paths of length 3, which are derived as product matrices (Table 3) of the respective Tables 1 and 2 matrices. The number of length 3 paths (Table 3, upper matrix) is greater than the number of paths of length 2. There are, for example, seven such paths from compartment 4 to itself: 4→4→4→4, 4→4→6→4, 4→5→9→4, 4→6→1→4, 4→6→4→4, 4→6→6→4 and 4→6→9→4. And there are fourteen length 3 paths from compartment 6 to 9: 6→1→1→9, 6→1→5→9, 6→1→9→9, 6→4→5→9, 6→4→6→9, 6→5→5→9, 6→5→9→9, 6→6→1→9, 6→6→5→9, 6→6→6→9, 6→6→9→9, 6→9→5→9, 6→9→6→9, and 6→9→9→9.

The cumulative influence, as fractional daily carbon flow, generated over these paths is 0.858 from 4 to 4, and 0.017 from 6 to 9 (Table 3, middle matrix). As in the case of the length 2 paths, the diagonal entries are smaller in value than the corresponding entries in Table 1 representing direct effects, but the nondiagonal values are greater indicating greater indirect influence over paths of length 3 than direct between these compartments.

Total influences over all paths of lengths 1 through 3 are given in the lower Table 3 matrix. The total effect of compartment 4 on itself over paths through length 3 is 2.710 (35% direct and 65% indirect), and for compartment 6 on 9 the value is 0.034 (18% direct and 82% indirect). Thus, at the level of length 3 paths, indirect effects already are becoming more important than direct ones.

The total effect of one compartment on another within a system is given by the cumulative influence propagated over all paths of all lengths connecting the two compartments. Thus, the matrix multiplication process continues, to form an infinite series which converges in the limit to a final, transitive closure matrix[15,16] in which all the influence over all paths of all lengths is fully accounted for. Of course, as path lengths increase the influence over any one of them becomes small, but the combinatorial increase in the number of paths may be dramatic enough that their cumulative influence is significant (Notes, i).

Tenth Order

Table 4 gives for the Figure 1 system the number of paths of length 10 (upper matrix), and the daily fractional carbon flow over these paths (middle matrix) and over all paths of all lengths through 10 (lower matrix). The combinatorial increase in number of paths is evident. For example, there are 40,619 paths of length 10 from compartment 4 to itself, and 80,937 from compartment 6 to 9. Numbers like these and the corresponding indirect influences shown in the middle Table 4 matrix, compared to the direct effects of the lower matrix of Table 1, seem incredible in view of the simplicity of the Figure 1 system. They are the basis for the proposition of this paper that in most biotically well developed ecosystems the preponderance of causality is

Table 3. Matrices for Indirect Paths of Length 3 in the Figure 1 Model.
***Upper:* Number of Length 3 Paths from Column to Row Compartments.**
***Middle:* Indirect Influence, as Daily Fractions of Carbon in Column Compartments, Transferred to Row Compartments Over Length 3 Paths.**
Lower: Total Influence, as Summed Daily Carbon Fractions of Column Compartments, Transferred to Row Compartments Over Paths of Lengths 1 Through 3.

		from								
		1	2	3	4	5	6	7	8	9
	1	3	1	0	3	1	5	0	4	4
	2	3	1	0	1	0	3	0	6	1
	3	12	5	1	6	4	14	0	15	10
	4	12	5	0	7	4	14	0	12	10
to	5	17	8	0	10	6	19	0	15	14
	6	9	4	0	6	4	11	0	7	9
	7	17	9	0	13	9	21	1	11	18
	8	0	0	0	0	0	0	0	1	0
	9	11	5	0	8	5	14	0	10	11

		from								
		1	2	3	4	5	6	7	8	9
	1	.729	>0	0	>0	>0	.009	0	.090	>0
	2	.071	.729	0	>0	0	>0	0	.024	>0
	3	.003	.053	.804	>0	>0	.009	0	.008	.002
to	4	.004	.004	0	.858	>0	.019	0	>0	.001
	5	.014	.011	0	.032	.857	.009	0	.001	.007
	6	>0	>0	0	.025	>0	.917	0	>0	.036
	7	>0	>0	0	.012	.008	.006	.857	>0	.005
	8	0	0	0	0	0	0	0	.562	0
	9	.023	>0	0	.001	.031	.017	0	.020	.939

		from								
		1	2	3	4	5	6	7	8	9
	1	2.439	>0	0	>0	>0	.019	0	.199	>0
	2	.154	2.439	0	>0	0	>0	0	.050	>0
	3	.068	.112	2.599	>0	>0	.018	0	.016	.003
	4	.009	.008	0	2.710	>0	.038	0	>0	.003
to	5	.028	.024	0	.065	2.710	.019	0	.001	.014
	6	>0	>0	0	.051	.001	2.833	0	>0	.073
	7	>0	>0	0	.025	.016	.013	2.710	>0	.011
	8	0	0	0	0	0	0	0	2.067	0
	9	.047	>0	0	.001	.064	.034	0	.041	2.876

Table 4. **Matrices for Indirect Paths of Length 10 in the Figure 1 Model.**
Upper: **Number of Length 10 Paths from Column to Row Compartments.**
Middle: **Indirect Influence, as Daily Fractions of Carbon in Column Compartments, Transferred to Row Compartments Over Length 10 Paths.**
Lower: **Total Influence, as Summed Daily Carbon Fractions of Column Compartments, Transferred to Row Compartments Over Paths of Lengths 1 Through 10.**

					from				
	1	2	3	4	5	6	7	8	9
1	21439	9304	0	14296	8305	26431	0	20956	20179
2	8822	3830	0	5883	3421	10875	0	8618	8305
3	60906	26431	1	40618	23600	75094	0	59548	57337
to 4	60906	26431	0	40619	23600	75094	0	59538	57337
5	85969	37306	0	57337	33313	106000	0	84045	80937
6	52084	22601	0	34736	20179	64219	0	50921	49032
7	108904	47256	0	72632	42190	134280	1	106482	102523
8	0	0	0	0	0	0	0	1	0
9	65642	28484	0	43779	25432	80937	0	64179	61797

					from				
	1	2	3	4	5	6	7	8	9
1	.349	>0	0	.001	>0	.019	0	.109	.001
2	.114	.349	0	>0	>0	.002	0	.109	>0
3	.069	.094	.484	.001	>0	.021	0	.022	.005
to 4	.009	.007	0	.601	>0	.047	0	.002	.006
5	.030	.022	0	.074	.600	.026	0	.005	.019
6	.004	>0	0	.063	.005	.754	0	.003	.100
7	.001	>0	0	.029	.018	.017	.599	>0	.015
8	0	0	0	0	0	0	0	.146	0
9	.052	.001	0	.006	.081	.048	0	.040	.812

					from				
	1	2	3	4	5	6	7	8	9
1	5.862	>0	0	.003	>0	.127	0	.984	.005
2	.888	5.862	0	>0	>0	.010	0	.316	>0
3	.466	.694	6.856	.004	.001	.133	0	.135	.028
to 4	.063	.050	0	7.632	.001	.292	0	.008	.031
5	.198	.155	0	.478	7.628	.155	0	.024	.112
6	.015	.002	0	.392	.019	8.578	0	.011	.594
7	.005	.002	0	.183	.117	.101	7.624	.002	.089
8	0	0	0	0	0	0	0	4.026	0
9	.338	.006	0	.024	.495	.282	0	.275	8.929

indirect, not direct. The influence over any one path may be small, but the total influence due to so many paths can be great.

For example, the total effect as fractional daily carbon flow of compartment 4 on itself over the 40,619 length 10 paths is 0.601 (Table 4, middle matrix), or 1.48 x 10^{-5} per path, which amounts to 63% of the direct effect of 4 on itself (0.950, Table 1, lower matrix). Similarly, the total influence of compartment 6 on 9 propogated over the 80,937 length 10 paths is 0.048 (Table 4, middle matrix), representing only 5.93×10^{-7} per path. The cumulative effect, however, is eight times the influence of the direct linkage from 6 to 9 (0.006, Table 1, lower matrix). The diagonal entries in the Table 4 middle matrix are smaller, and the nondiagonal values larger, than in any of the previously illustrated corresponding matrices. Thus, while self influences (diagonal elements) due to paths of increasing lengths are decreasing steadily, at the level of length 10 paths, intercompartmental influences (nondiagonal entries) are still increasing with path length. Eventually, this trend must reverse for the series of partial influence matrices to converge to a final matrix of total influences.

The lower matrix of Table 4 shows that the total effect of compartment 4 on itself over paths through length 10 is 7.632 (12.4% direct and 87.6% indirect), and for compartment 6 on 9 the total influence is 0.282 (2.1% direct and 97.9% indirect). Thus, at the level of length 10 paths, higher order effects are already very predominant over direct ones.

Infinite Order

The final convergent matrix for the Figure 1 model is shown in the upper matrix of Table 5, which represents the total influence as fractional daily carbon flow propagated over all paths of all lengths in the system. Comparison with the lower matrix of Table 4 indicates that paths through length 10 hardly begin to account for all the influence in this model. For example, paths of lengths 1 through 10 account for 37.6% (7.632/20.298) of the carbon flow from compartment 4 to itself, but for only 1.8% (0.282/15.302) of the flow from compartment 6 to 9. Comparing the lower Table 1 matrix with the upper matrix of Table 5, the direct influence of compartment 4 on itself (0.950) represents only 4.7% of the total (20.298), and that of compartment 6 on 9 (0.006) only 0.04% of the total (15.302). Indirect effects in the system are summarized in the middle matrix of Table 5, which represents total influence (upper matrix) less direct effects (Table 1, lower matrix). The preponderance of causality propagated as carbon flow in the Figure 1 model is obviously indirect, not direct.

CONCLUSION

The numbers generated in this simple exercise are impressive. Natural ecosystems must be even more impressive. Real ecosystems have hundreds or thousands of species; the number of causal paths connecting each pair of them must be truly astronomical in most cases. What we have is a situation where influence is propagated so broadly and diffusely in ecosystem networks that its origins for all practical purposes cannot be traced. Add dynamics to the network model, and the situation becomes even more complex. Only direct causes are experienced instantaneously; as path length increases so does the time from source to destination. System components that have long since gone out of existence could still be exerting significant influence at any given locus.

Science is not going to deal easily with these realities, which manifest the core of holistic philosophy. The predominance of indirect causality in ecological networks is going to challenge biology right down to its roots. For example, a central consequence of organism-environment separatism is the paradigm of adaptation, strongly rooted in Darwinism. But how may species adapt, much less develop adaptive strategies (Notes, c), in ecosystem networks where there is little relationship between the immediate signals (direct causes) upon which adaptation is based and the total causality emanating from a source? This might be possible if a constant relationship existed between the direct and indirect causes, so that adjustment to the first might automatically provide or imply adaptation to the second. The lower matrix of Table 5, giving indirect/direct influence ratios for the Figure 1 model, dispels this possibility immediately. Not counting the ∞ values denoting division by zero, there are one to three orders of magnitude variation in these ratios for the

Table 5. ***Upper:*** **Transitive Closure Matrix for the Figure 1 Model of Total Influence, as Summed Daily Carbon Fractions of Column Compartments, Transferred to Row Compartments Over all Paths of all Lengths.**
Middle: **Total Indirect Influence, as Summed Daily Carbon Fractions to Row Compartments Over all Paths of all Lengths > 1.**
Lower: **Ratios of Total Indirect Influence (Middle) to Direct Influence (Table 1, Lower) from Column to Row Compartments (∞ Denotes Division by 0, i Denotes Indeterminate, 0/0).**

	from								
	1	2	3	4	5	6	7	8	9
1	9.097	.013	0	.311	.201	1.472	0	2.359	.906
2	2.964	9.004	0	.091	.059	.432	0	1.217	.266
3	2.833	3.017	13.286	.536	.418	2.444	0	1.115	1.881
to 4	.852	.340	0	20.298	.920	6.032	0	.394	4.137
5	1.957	1.008	0	5.861	20.239	5.141	0	.745	5.570
6	2.872	.391	0	9.243	5.982	42.704	0	1.853	26.894
7	.532	.127	0	2.796	2.019	3.289	19.000	.305	4.042
8	0	0	0	0	0	0	0	4.714	0
9	5.933	.646	0	5.765	12.971	15.302	0	3.939	57.310

	from								
	1	2	3	4	5	6	7	8	9
1	8.197	.013	0	.311	.201	1.468	0	2.318	.906
2	2.934	8.104	0	.091	.059	.432	0	1.207	.266
3	2.821	2.996	12.356	.536	.418	2.441	0	1.112	1.880
to 4	.338	.338	0	19.348	.920	6.025	0	.394	4.137
5	1.952	1.004	0	5.850	19.289	5.137	0	.745	5.568
6	2.872	.391	0	9.234	5.982	41.733	0	1.853	26.881
7	.532	.127	0	2.791	2.016	3.287	18.050	.305	4.040
8	0	0	0	0	0	0	0	3.889	0
9	5.924	.646	0	5.765	12.960	15.296	0	3.932	56.331

	from								
	1	2	3	4	5	6	7	8	9
1	9	∞	i	∞	∞	489	i	58	∞
2	101	386	i	∞	∞	∞	i	134	∞
3	235	143	13	∞	∞	814	i	371	1880
to 4	425	338	i	20	∞	861	i	∞	∞
5	390	251	i	488	20	1712	i	∞	2784
6	∞	∞	i	1026	∞	43	i	∞	2068
7	∞	∞	i	698	672	1644	19	∞	2020
8	∞	i	i	i	i	i	i	5	i
9	658	∞	i	∞	1178	2549	i	492	58

different compartments. For example, in its relationships to food source compartments, pelagic carnivores (3) have indirect / direct carbon flow ratios ranging from 13 to 1880 (row 3, lower Table 5 matrix). It is doubtful under these circumstances that the pelagic carnivore populations could meaningfully adapt to their prey populations based only on dietary composition of the latter. It is doubtful from the Table 5 figures in general how adaptation of any kind could be possible in the Figure 1 system. And it seems even more absurd to think that adaptation could occur in real, temporally dynamic ecosystems. Adaptation, so long as it must be linked to the variables of direct experience by the organism or population, is unlikely to provide much of the final explanation of how parts work within whole systems in nature.

The state of ecology is relevant to environmental concerns, for environmental protection can fare no better than the theory in which its practice is rooted. Throughout the 1980s we can expect to see repeated efforts to manage populations, establish safe standards for exposure to hazardous substances, and otherwise mitigate problems of the environment to end in frustration and dismay. Billions will be spent on meaningless environmental monitoring, but nearly no resources will be aimed at the exposition of the systems nature of environment which is at the heart of every difficulty. The decade will have its own litany of failures and its own lexicon of events and substances which frighten us all. If it can only be realized sooner rather than later that wholeness and indirect causality are the key missing ingredients in present understanding and approaches, perhaps our own adaptive response during the 1980s might make it possible to enter the new century with an environmental science that is precise, quick and sure. The key to this aspiration is ecosystem.

ACKNOWLEDGEMENTS

I acknowledge with thanks the technical assistance of M. Craig Barber, Susan L. Durham, Randall E. Hicks, and Elizabeth F. Vetter of Ecology Simulations, Inc. This is University of Georgia's, *Contributions in Systems Ecology*. No. 55.

NOTES

a. Mason and Lagenheim[1] define *environmental phenomena* as those that actually or potentially have an operational relation with any organism. The *environmental relation* of an organism is the sum of empirical relations between the environmental phenomena and any individual organism. The set of environmental relations of an organism constitutes the relation of *natural selection*. The *operational environment* of an organism consists of those instantaneous environmental phenomena that actually enter a relation with the organism; the concept applies to specific individual organisms. *Potential environment* consists of environmental phenomena which may enter an environmental relation at some point in the ontogeny of an organism. "The environment of any organism is the class. . .of those phenomena that enter a reaction system of the organism or otherwise directly impinge on it to affect its mode of life at any time throughout its life cycle as ordered by the demands of the organism or as ordered by any other condition. . .that alters its environmental demands." *Nonenvironment* consists of all phenomena (indirect, historical or organism caused) which never enter into a direct environmental relation with the organism. "[Indirect and historical] factors both function to condition a phenomenon. . .to which an organism then reacts. Important as this is to the ecosystem, the only [organism] reaction. . .is to an already conditioned phenomenon. The state of a phenomenon prior to its conditioning is outside the scope of. . .*operational*. . .and. . .*potential environment* *** It follows that we must reject the implication that. . .[causal] chains constitute a unitary event playing a significant role in the environmental relation even though the steps are very important to the ecosystem *** There is also a philosophical reason for removing indirect factors from the concept *environment*. To introduce indirect factors into causal relations within the environment is to introduce an infinite regress into the system of explanation. Every cause has in turn itself a cause which becomes an indirect cause of the most recent effect. The regress is toward the limbo of ultimate cause along an infinitely reticulating path; for this we have neither finite description nor finite explanation. . . To include such relations in environment is to confuse environment with its history." Direct causes only are admitted in the orthodoxy of environment.

b. J. Grinnell[2] originated the niche concept with his description of the niche of the California thrasher (*Toxostoma redivivum*). Three classes of environmental factors were significant. *Zonal factors* included chapparal vegetation, temperature, altitude, slope, exposure and humidity. *Associational factors* were evergreeness, height, cover and vegetation. *Faunal factors* referred to migration. Of these factors Grinnell wrote, "These various circumstances, which emphasize dependence on cover and adaptation in physical structure and temperament thereto, got to demonstrate the nature of the ultimate associational niche occupied by the California thrasher." C. Elton[3] had a functional orientation for the niche, but it did not go beyond direct factors: "It is. . .convenient to have some term to describe the status of an animal in its community, to indicate what it is *doing* and not merely what it looks like, and the term used is 'niche.' *** the 'niche' of an animal means its place in the biotic environment, *its relations to food and enemies.*" G. E. Hutchinson[4] defined the *fundamental niche* of an organism as a direct factor hyperspace bounded by upper and lower limits of physical and biological variables permitting "indefinite existence" or "persistence" in an ecosystem. His *realized niche* referred to conditions in the ecosystem in terms of the same factors which form the axes of an organism's fundamental niche. Niche in ecology traditionally ignores indirect factors. Vandermeer[5] considered Hutchinson's fundamental niche to be preinteractive, its axes restricted to abiotic variables. *Partial niches* (postinteractive) are defined as species are added to an assemblage. Whether the extant species interact directly or indirectly is not considered, but each empirically defined partial niche of an organism as a function of all species present at least leaves open the possibility of indirect interactions between them. Recently, Levine[6] has made this possibility explicit in his *extended niche* concept which represents the beginning of movement away from the classical direct factor niche (see also, References 7 and 8).

c. It has become stylish to attribute purposeful activity to improbable biological objects, as indicated by a sampling of recent titles from *The American Naturalist*, 113-114 (1979) and 115-116, No. 2 (1980, current issue): "Long- and short-term dynamic optimization models with application to the feeding strategy of the logger head shrike," "Classifying species according to their demographic strategy. . .," "Alcoholic fermentation in swamp and upland populations of *Nyssa sylvatica*: temporal changes in adaptive strategy," "A note on the evolution of altruism in structured demes," "The origin of the 'adaptive landscape' concept," "Is a super territory strategy stable?," "The evolution of sex-ratio strategies in Hymenopteran societies," "The strategy of the red algal life history," "Barking in a primitive ungulate, *Muntiacus reevesi*: function and adaptiveness," and "Enzyme polymorphism and adaptive strategy in the decapod Crustacea." Waddington's *The Strategy of the Genes*[9] and Dawkins' *The Selfish Gene*[10] are a delight as metaphors, but in population and evolutionary ecology metaphor is not always very distinct from explanation.

d. Ecological psychologists have written against this dualism in favor of organism-environment synergy. The organism and its environment are a unitary whole, mutually compatible, complementary and co-implicative.[11,12,13]

e. The ecosystem model is under development by Ecology Simulations, Inc., Athens, Georgia, for the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce (Contract No. NA-79-SAC-00790). Its purpose is brine impact assessment in the northwestern Gulf of Mexico as part of the Strategic Petroleum Reserve Program. The model's authors are M. Craig Barber, Susan L. Durham, Randall E. Hicks, and Elizabeth F. Vetter. The present version consists of the following major functional compartments, each containing one or more levels of subcompartments. The Plankton groups are: Nannophytoplankton and Net Phytoplankton, which are obligate autotrophs;

Facultative Auto/heterotrophs; and heterotrophic categories Bacterioplankton, Microzooplankton, Holomucus Feeders, Meromucus Feeders in two stages, Feeding and Nonfeeding, Raptorial Feeders, Holograzers in Feeding and Nonfeeding stages, Benthic Meroplankton both Feeding and Nonfeeding, and Nektronic Meroplankton Feeding and Nonfeeding. The Benthic Submodel principal categories are Microheterotrophs, Permanent and Temporary Microfauna, Mucus, Tentaculate and Filtering Suspension Feeders, Selective and Nonselective Deposit Feeders, and Raptorial Feeders. The major Organic Complex compartments are Fecal Material, Organic Aggregates, Fine Particulate Organic Carbon, Pelagic Dissolved Organic Carbon, Pelagic Dissolved Inorganic Carbon, Benthic Particulate Organic Carbon, in two categories, Surface and Subsurface, and Benthic Dissolved Carbon, both Organic and Inorganic. The principal categories of the Nekton Submodel reflect different types of life history ontogenies, including trophic relationships, and patterns of migration and spawning. They are defined according to feeding and excretion habits and locations. The compartments and representative genera and species in them are: Pelagic Planktivores (*Anchoa* spp., *Peprilus burti* and *Polydactylus octonemus*), Pelagic Carnivores (*Cynoscion* spp. and *Trichiurus lepturus*), Pelagic Omnivores (*Chloroscombrus chrysurus* and *Loligo* sp.); the members of these first three categories feed and excrete mainly in the water column; Demersal Carnivores (*Etropus crossotus* and *Porichthys porosissimus*) feed mainly in the water column and excrete in the benthos; Switch Feeders (*Arius felis*, *Stellifer lanceolatus* and *Stenotomus caprinus*) feed mainly in the benthos and excrete into benthic detritus; and Reef Type Schoolers (*Haemulon macrostomum* and *Lutjanus campechanus*) feed principally in the benthos nocturnally and excrete in the water column diurnally. These compartments and their subcompartments are interconnected by carbon flows, and they interact with the ecosystem's environment by a multitude of processes, including primary production, longshore transport, onshore-offshore migrations, human harvesting activities, and destructive influences of wave fronts and storms. The whole ecosystem model would illustrate the importance of influences in networks more strongly, but the Nekton Submodel by itself makes an adequate and less overwhelming case.

f. M. Craig Barber, Elizabeth F. Vetter, and Susan L. Durham formulated the dietary compositions in Table 1 based on data drawn from R. J. Conover[18] and R. M. Rogers.[19] These Table 1 diets, which represent daily fractions of carbon in prey compartments transferred to predator compartments, were derived from data which are basically predator compartment oriented (e.g., stomach analyses) by the following procedure developed by Barber. Let f_{ij} be the daily food (carbon) ration from compartment j to i in an n compartment system ($i, j=1,\ldots,n$). With x_i the standing crop of predator i, the daily turnover rate of this compartment is $T_i^{-1} = \Sigma_{j=1}^{n} f_{ij}/x_i$. Turnover time T_i and f_{ij} data can be used to calculate a retrospective Markov chain $\{\xi'(t)\varepsilon\{x_1,\ldots,x_n\}, t=0,-1,-2,\ldots\}$, in which the random variable $\xi'(t)$ designates the compartment $x_1,\ldots,x_n$ in which a unit of carbon resides at time t. Under two assumptions $\xi'(t)$ can be manipulated to yield a forward Markov chain, $\{\xi''(t)\varepsilon\{x_1,\ldots,x_n\}, t=0,1,2,\ldots\}$, and hence donor oriented food transfer rates: (1) the transition probabilities of $\{\xi'(t)\}$ must be time invariant, and (2) the state space $\{x_1,\ldots,x_n\}$ must be such that any state x_i can be reached from any state x_j in a finite number of state transitions. An ergodic set of states was achieved by closing the {Plankton, Nekton, Benthos, Organic Complex} system. Then the {Plankton, Nekton, Benthos} subsystem could be represented as in Figure 1 and Table 1 as an open system with Organic Complex compartments as environment. Let $a'_{ij} = f_{ij}/x_i$ be the fraction of predator i's daily diet that comes from donor j. The fraction a''_{ij} of prey j's standing crop contributed daily to predator group i, i.e., $f_{ij} = a''_{ij} x_j$, is obtained as follows. One-step transition probabilities $p'_{ji} = P[\xi'(t-1) = x_j | \xi'(t) = x_i]$ for the reverse Markov chain $\{\xi'(t)\}$, modeling the history of carbon flows, can be formulated as $p'_{ji} = a'_{ji} T_i$ for $i \neq j$, and $p'_{ji} = 1 - T_i (a_{i0} + a_{ii})$ for $i = j$, where 0 denotes environment. If $P[\xi'(t) = x_k] = u_k$ a constant, $k=1,\ldots,n$, where $\sum_{k=1}^{n} u_k = 1$, then $\{\xi''(t)\}$ can be constructed from $\{\xi'(t)\}$ in the following manner: Since $p'_{ji} = P[\xi'(t-1) = x_j | \xi'(t) = x_i] \triangleq P[\xi'(t-1) = x_j \cap \xi'(t) = x_i] / P[\xi'(t) = x_i]$, then $p'_{ji} = P[\xi'(t-1) = x_j] / P[\xi'(t-1) = x_i] = (P[\xi'(t-1) = x_i \cap \xi'(t) = x_j] / P[\xi'(t-1) = x_i])(P[\xi'(t-1) = x_j] / P[\xi'(t) = x_j])$. If $P[\xi'(t-1) = x_j] = P[\xi'(t) = x_j] = u_j$, then $p'_{ji} (P[\xi'(t-1) = x_j] / P[\xi'(t-1) = x_i)$ reduces by definition to $P[\xi'(t) = x_i | \xi'(t-1) = x_j]$. This is a one step transition probability p''_{ij} for a forward Markow chain $\{\xi''(t)\}$, whose relationship to the Table 1 daily fractional transfers a''_{ij} is $p''_{ij} = a''_{ij} T_j$, where T_j is turnover time of the prey compartment j.

g. It is the principle that indirect causality or influence in an interactive network it is important which is to be demonstrated. "Influence" may be manifested in many different ways in a real system, involving objective and subjective, quantitative and qualitative, processes. In the Figure 1 model carbon is taken as a surrogate for general causality. It is assumed that influence can be modeled and quantified in a manner analogous to Table 1. Then, the properties to be developed from Table 1 are general and not especially restricted to carbon flow, which serves in this instance merely as a concrete example.

h. M. Craig Barber performed the calculations for Tables 2-5.

i. The proliferation of paths also is pertinent to ecosystem diversity and stability considerations. R. H. MacArthur[20] touched off a long standing controversy in ecology when he suggested in a network (food web) context that species diversity confers community stability: "Where there is a small number of species (e.g., in arctic regions) the stability condition is hard or impossible to achieve. . . Where there is a large number of species (e.g., in tropical regions) the required stability can be achieved. . ." Resolution of the controversy has been inconclusive, bogged down on the finer points of exact definitions and measures of both diversity and stability, and other technical problems. MacArthur wrote about food webs that, "Stability increases as the number of links increases." This might now be extended to read, stability increases as the number of paths increases, where a path may be direct (a "link") or indirect between any two species or compartments. All the paths of all lengths between two compartments represent alternative routes; they are parallel in the network no matter how tortuous. J. Hill and S. L. Durham[21] have recently suggested an alternative mechanism to feedback control in ecosystem stability, labeled "congeneric homotaxis." Hill[22] writes of this concept: "Congeneric homotaxis is a prototype concept, a new hypothesis of control *** The term congeneric homotaxis identifies a control mechanism resulting from many functionally similar, related or congeneric components. These exist in a similar or homotaxial position in the system structure but each has differing responses to noise or system inputs *** The preferred connotation of the term homotaxis is that of an abstract control mechanism. . .[which] results from the parallel connection of components that are functionally identical with respect to one input but only functionally similar with respect to another. . . For example, a community of phytoplankton, consisting of species with differing optimal temperatures of nutrient uptake rates, exhibits an insensitivity (controlled response) of total biomass to temperature variation, nutrient fluctuations, and even species extension. . .that results from congeneric homotaxis." Hill and I discussed mechanisms of network control in the context of consumer regulation of ecosystems several years before he identified the specific mechanism described above. The focus then was on locating keystone positions in the network to become occupied by evolutionarily "expensive," and therefore highly reliable, species (i.e., the top consumers) which would exert control by virtue of topological position. An example of control of this type is:[8,17] top consumers in a cold spring ecosystem model control the bacteria, to which they are not at all directly connected, through a set of parallel paths of indirect influence, whose first branch is a direct feedback linkage to detritus which is only 1.4% of the value of total system input. Congeneric homotaxis, as presented, is interesting but too direct factor oriented. "Congener" means a closely similar functional form. The real basis for network stability, I would argue, is parallel paths, many of them, each carrying but a small portion of the total influence between any pair of components. The paths may be very long, and hence many species of many different functional types, i.e., noncongeners, may be involved in them. Since the influence over any one path is small, interruption of propagation over that path would have negligible effect on system stability. This was the logic of MacArthur's original concept, which he then went on to embody in the Shannon-Wiener function as a stability measure ($-\Sigma p_i \log p_i$, p_i the probability of food transfer over the i'th path in the network): "The amount of choice which the energy has in following the paths up through the food web is a measure of the stability of the community."[20] This amount of choice, i.e., paths existing in parallel, increases combinatorially with the number of species in the system. Thus, in context of the proliferation of parallel paths of increasing length, which the present paper reveals as an inherent property of system networks, MacArthur's original idea seems just as reasonable today as when he originally proposed it. Community diversity confers path diversity confers stability. If homotaxial congeners help maintain the integrity of parallel paths, so much the better. The only thing MacArthur lacked was the transitive closure formulation[15,16] for exhausting all the paths.

REFERENCES

1. Mason, H. L., and J. H. Langenheim. 1957. Language and the concept of environment. Ecology. 38:325-430.
2. Grinnell, J. 1917. The niche-relationships of the California thrasher. Auk. 34:427-433.
3. Elton, C. 1927. Animal Ecology. Sidgwick and Jackson. London, England.
4. Hutchinson, G. E. 1957. Concluding remarks. *In* Cold Spring Harbor Symp. Quant. Biol. 22:415-427.
5. Vandermeer, J. H. 1972. Niche theory. Ann. Rev. Ecol. Systemat. 3:107-132.
6. Levine, S. H. 1977. Exploitation interactions and the structure of ecosystems. J. Theor. Biol. 69:345-355.
7. Patten, B. C., and G. T. Auble. 1980. Systems approach to the concept of niche. Synthese. 43:155-181.
8. Patten, B. C., and G. T. Auble. 1981. System theory of the ecological niche. Amer. Nat. 117:893-922.
9. Waddington, C. H. 1957. The Strategy of the Genes. Allen and Unwin. London, England.
10. Dawkins, R. 1978. The Selfish Gene. Oxford Univ. Press. New York, N.Y.
11. Gibson, J. J. 1977. The Ecological Approach to Visual Perception. Houghton-Mifflin. Boston, Mass.
12. Turvey, M. T., and R. Shaw. 1979. The primacy of perceiving: an ecological reformulation of perception for understanding memory. *In* Perspectives on Memory Research. L. G. Nilsson, ed. Erlbaum. Hillsdale, N.J.
13. Shaw, R., M. T. Turvey, and W. Mace. 1979. Ecological psychology: the consequences of a commitment to realism. *In* Cognition and the Symbolic Processes. Vol. 2. W. Weimer and D. Palermo, eds. Erlbaum. Hillsdale, N.J.
14. Patten, B. C., and M. Witkamp. 1967. Systems analysis of 134 cesium kinetics in terrestrial microcosm. Ecology. 48:813-824.

15. Patten, B. C., R. W. Bosserman, J. T. Finn, and W. G. Cale. 1976. Propagation of cause in ecosystems. *In* Systems Analysis and Simulation in Ecology. Vol. 4. B. C. Patten, ed. Academic Press. New York, N.Y.
16. Patten, B. C. 1978. Systems approach to the concept of environment. Ohio J. Sci. 78:206-222.
17. Patten, B. C. 1982. (In Press) Environs: relativistic elementary particles for ecology. Amer. Nat.
18. Conover, R. J. 1978. Transformation of organic matter. pp. 221-500. *In* Marine Ecology. O. Kinne, ed. Wiley Publishing Company. New York, N.Y.
19. Rogers, R. M. 1977. Trophic interrelationships of selected fishes on the continental shelf of the northern Gulf of Mexico. Ph.D. Dissertation. Department of Oceanography. Texas A and M University. College Station, Texas.
20. MacArthur, R. H. 1955. Fluctuations of animal populations, and a measure of community stability. Ecology. 36:533-536.
21. Hill, J., and S. L. Durham. 1978. Input, signals and controls in ecosystems. pp. 391-397. *In* Proc. IEEE Conf. on Acoustics, Speech and Signal Processing. Institute Electrical and Electronic Engineers.
22. Hill, J. 1980. Influence: a structural measure of the organization of systems. Ph.D. Dissertation. The Institute of Ecology. University of Georgia. Athens, Ga.

UNDERSTANDING THE ECOLOGICAL VALUES OF WETLANDS

Joseph S. Larson

WHAT ARE WETLANDS?

Wetland? In 1970 the term meant little to the real estate developer, lawyer or engineer. Only to wildlife biologists and in certain New England states did the term wetland have a more significant general meaning. Of course, most people had some idea of what marshes, flats, swamps and bogs were. Pocosins, sloughs, hammocks and bays were familiar in certain parts of the nation. Fens and carrs were known to special groups of ecologists. All of these (plus other places known by other names) are today recognized as various kinds of wetlands.

Wildlife biologists were early users of the term because areas on the landscape that are dominated by water and water tolerant plants provide essential habitat to furbearing mammals, migratory ducks, geese and swans as well as many other wading, water and shore birds. If these species were to survive in the face of human development, wildlife professionals had to preserve all sorts of wet habitat that was conveniently lumped under the name wetland. In short, wetlands are areas on the landscape where water is present at, near or above the surface of the land long enough to be the primary factor dictating what kinds of plants will grow there and what special types of soil are formed (Figures 1 and 2).[1]

Wetlands are where you find trees, shrubs, grasses, rushes, reeds or herbaceous plants that are adapted in some physical way or have developed physiological processes that permit them to grow where water is the dominant element year-round or during a portion of the growing season. The soils on these wetland sites also reflect the influence of water. Many of them are mucks or peats that contain organic matter from the wetland plants. Some have particular physical, chemical or color characteristics that develop due to continuous or long periods of water saturation. Some wetlands, like rocky coastal shores, may have clinging plants and no soil. Others, such as beaches, bars and flats, have no vegetation and technically no "soil," but rather a sand, gravel or silt base.

A DECADE OF CHANGE IN ATTITUDES TOWARD WETLANDS

Wetlands, let alone swamps, just were not fit subject for polite dinner table conversation 10 years ago. In a Maryland farmhouse, a Texas ranch or a Florida bungalow, the word bog or swamp was usually linked to mosquitoes, malodorous vapors, dangerous reptiles or desperate men driven from comfortable and "proper" society. A good swamp was a drained or filled swamp. To most people, wetland translated to wasteland. During the late 1960s and even more so during the 1970s, however, wetlands took on a different (and sometimes controversial) public image.

The Author: Dr. Joseph S. Larson received the B.S. and M.S. degrees from the University of Massachusetts and the Ph.D. from Virginia Polytechnic Institute. He is Chairman of the Department of Forestry and Wildlife Management at the University of Massachusetts, Amherst and Executive Chairman of the National Wetlands Technical Council.

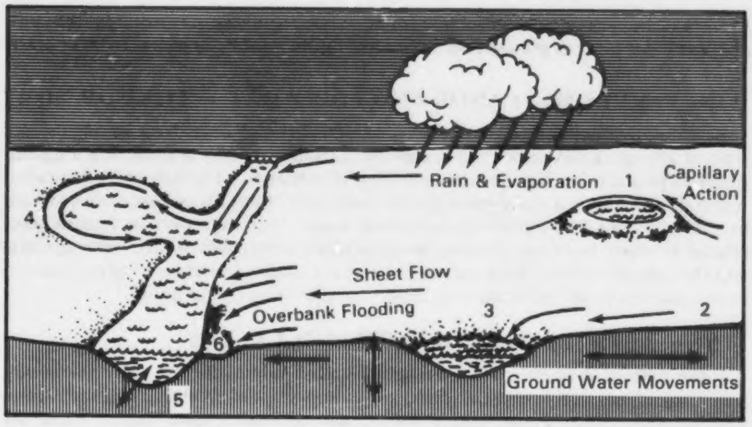


Figure 1. A schematic representation of 6 types of freshwater marsh environments, and their hydrologic regime.[30]

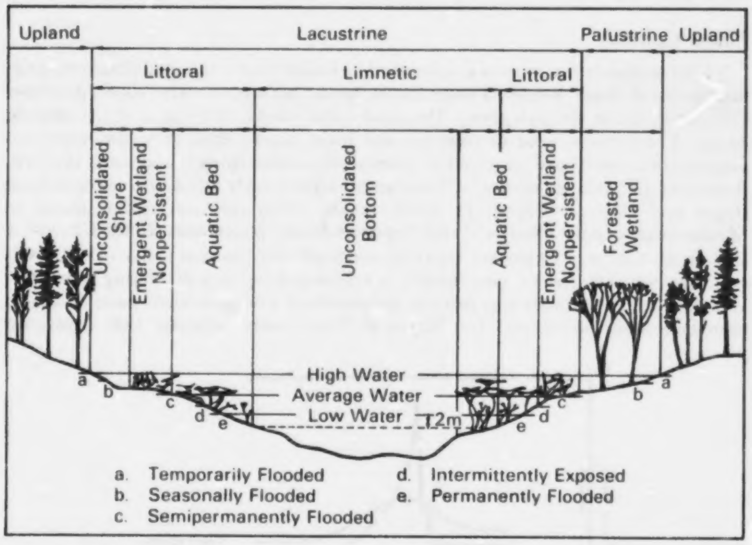


Figure 2. A cross-section of a typical lacustrine (Lake-side) wetland.

Many a farmer, rancher or developer found himself thinking very different thoughts about that wet piece of ground that no one had found the time or means to fill or drain.

WHO VALUES WETLANDS AND FOR WHAT — THEN OR NOW?

By the turn of the decade new views of wetlands had developed among certain interest groups. These views had caused the legislative bodies in some New England states to pass laws to regulate the alteration of wetlands.[2] The new attitude toward wetlands arose from a recognition that in many cases these areas were closely related to critical events and conditions involving water. Wetlands were in various ways related to water in excess (floods), water in short supply (dry wells), water quality, and the success of the fishing industry. These are health, welfare and safety issues—issues that made any selectman or county commissioner take notice.[3]

A NEW APPRECIATION OF WETLAND VALUES

If the welfare of wildlife had not interested most public officials, these new issues, with their highly visible economic and social impacts, did. Wetland wildlife habitat that had been tolerated only until it could be altered to serve some "higher" social use was now being identified as serving some unexpectedly important ecological functions. These functions translated into social values and political concerns that affect the pocketbook and the ballot box. Indeed, fish and wildlife habitat concerns were in some ways supplanted by concerns that attracted wider public attention. Nevertheless, fish and wildlife resources stood to reap important benefits—even if they were now in a very secondary role. An examination of the appreciation for wetland functions and values, as they developed over the decade of the 1970s, make this point more clearly.

Flood Control

Inland wetlands function in a watershed as basins that retain and detain water at various flood stages. **Retained water leaves the surface water system via evaporation** and transpiration through plants. Detained water is held temporarily in the wetland basins. These basins tend to receive water more rapidly than they can empty out because their outlets are restricted or because vegetation spreads and slows the flow. Retention and delayed release of flood waters significantly affect downstream flood stages and damage (Figure 3). Early in the 1970s this was demonstrated in **Massachusetts in the Charles[4,5] and Neponset River[6] watersheds. In the Charles, a** U.S. Army Corps of Engineers' study documented that "natural valley storage" was cost effective. The federal government is now acquiring and protecting over 8,000 acres of natural wetlands that provide natural flood storage at costs more favorable than man-made structures. The Neponset River study indicated that significant

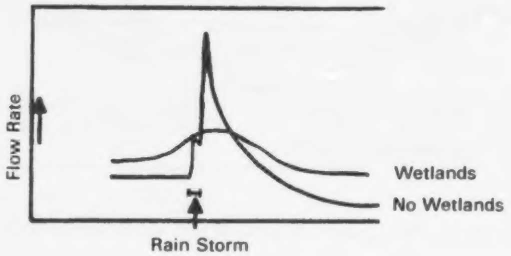


Figure 3. Effect of wetlands on stream flow following a rain storm.[31]

increases in down stream flooding occurs with the loss of 25-50 percent of the wetlands in the watershed. The Eastern Water Law Center of the University of Florida College of Law[7] has developed a model surface water runoff control ordinance that recognizes the role of wetlands in regulating water runoff. In 1975 the Natural Resources Defense Council reviewed the flood control value of wetlands for the Federal Insurance Administration and urged that agency to adopt regulations that recognize this wetland function.[8]

Dollar values of the water retention and detention functions of wetlands have been developed for a very few sites. Such values are valid for these particular sites and cannot be generalized to other areas. However, it is interesting to note the Charles River study estimated that the greater Boston area would be spared flood losses of $647,000 annually by the year 2000. If this is viewed as a kind of return or interest received from protecting or investing in wetlands, one can say that each wetland acre has a value equal to $1,488 put in the bank at an interest rate of about 5 percent.[9] Since 1970 (and as recently as 1979) both the U.S. Army Corps of Engineers[10] and the Massachusetts' office of the U.S. Soil Conservation Service (SCS)[11] have developed trial or "rule of thumb" techniques for evaluating the flood control values of wetlands. These approaches numerically rate wetlands according to actual storage, the effectiveness of the storage, the need for control downstream, damage potential, or calculated factors based on percent of a watershed in wetlands. The flaw in the dollar values generated by these procedures is the dependence upon downstream-made structures to generate economic values or calculate avoided losses. Wetlands that effectively detail flood waters on streams that have little man-made development are rated low in flood control value. This ignores the value of current land uses that do not involve structures as well as the loss of future opportunities for alternative land uses if the flood detention function is impaired. The efforts to understand the flood control function of wetlands have been very exciting, but it would seem that hydrologists have much more to do in applying their technology more effectively to wetland flood control than has been done to date. For example, studies of the relations of wetlands to flood control in unglaciated areas of the United States are lacking.

Storm Damage

Coastal wetlands have become regarded as landscape units that protect fastlands from erosion, and act as buffers against coastal flooding and sea level rises. In 1974 research workers at the Virginia Institute of Marine Science reported that saline marsh vegetation can absorb or dissipate wave energy and establish a dense root system that stabilizes the soil.[12] They also reported that freshwater species were less effective in this regard and that the peat substrate of some marshes acts as a giant sponge in receiving and releasing water.

In the early 1970s they developed a ranking system for use in the Virginia wetland regulation program that rates 12 coastal wetland plant communities for effectiveness as buffers against erosion and flood. But actual experimental testing of this role of coastal wetlands has not been conducted. University of Michigan wetland researchers in 1978 stated that where physical processes combine to produce shore erosion, the energies involved are likely to prevent the establishment of wetland communities.[13] This assumed function of coastal wetlands requires further study before it is widely used as a basis for regulation.

Water Quality

In the anaerobic soils of wetlands the process called denitrification removes nitrogen from the water and during the growing season plants remove nitrogen and phosphorous from wetland soils and water. Researchers at Louisiana State University's Center for Wetlands[14] have suggested that this function is a form of natural tertiary treatment that has an income capitalized value in southeastern tidal marshes of $50,000 per acre. This assumes that the replacement of this function, following wetland destruction, would require construction of a tertiary treatment facility. The potential for managing freshwater wetlands for removal of excess nutrients has been studied in various parts of the world.[15] In the United States such diverse communities as cypress domes[16] and northern peat marshes[17] have been intensively studied for their potential to treat waste water. In addition to nutrient removal, wetlands may at times remove significant amounts of metals and reduce the sediment load transported in streams.[18] Figure 4 illustrates some of the forces that govern these activities in a lakeshore wetland.

Techniques for assessing the role of individual wetlands for this role in water quality control are crude. It may be that estimates of primary productivity of a site may be useful.[18] In Virginia[12] guidelines for regulating wetland alteration rank plant communities in their ability to act as sediment traps. If the current estimates of tertiary treatment value are at all reasonable, and if there is high potential for using some wetlands to treat effluent, then there is a critical need to translate knowledge developed in the past decade into evaluation procedures that can be used in practical wetland regulation.

Fish Nursery

The bulk of the United States' commercial fish catch, by weight and value, and the saltwater sport fish catch, by weight, are dependent upon coastal estuaries and their wetlands for food sources, spawning grounds, nurseries for the young, or for all of these purposes.[19] The importance of the fin and shellfish industry and the general acceptance of these roles of coastal wetlands have persuaded most coastal states and communities that wetlands are "fish nurseries." Protection of these functions was the purpose of the earliest wetland legislation. These functions have been so well accepted by the public that no techniques have been developed to rank or rate specific wetlands for this value. Some state regulations single out certain wetland plant communities for protection of these functions but this is usually based on the rate of primary productivity.

Freshwater wetlands have not received as much attention as coastal wetlands for their role as "fish nursery" areas. Studies in Michigan during the past decade have

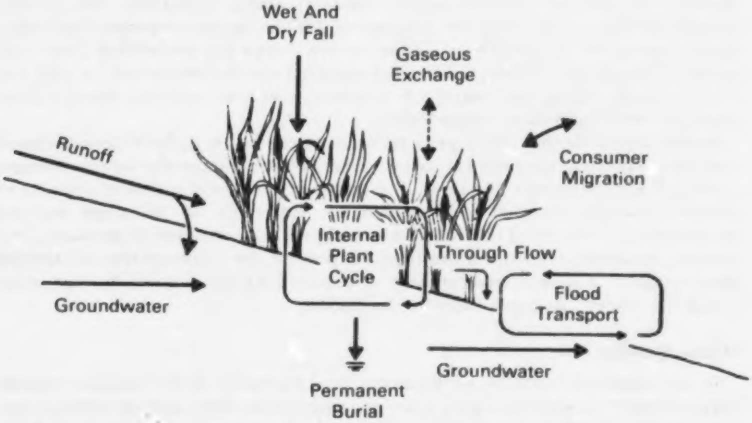


Figure 4. A conceptual input-output model for a lakeshore wetland.[32]

identified northern pike, carp, and yellow perch and possibly smallmouth bass as wetland dependent spawners. Degradation and elimination of wetlands have been associated with collapse of the commercial fisheries of northern pike, muskellunge, lake sturgeon and whitefish in the Great Lakes.[20] Tilton, et al.[13] have used capital cost and annual expenses of purchasing wetlands and constructing wetlands to develop estimates that an acre of purchased wetlands had a 1978 worth of $10,644 and constructed wetlands a $22,276 value for northern pike production.

The SCS wetland evaluation system in Massachusetts represents the sole attempt to develop a comparative rating system for freshwater wetlands as fish habitat.[11] It places relative numerical rankings for fish habitat on wetlands that abut open water. It is based simply on the size of the permanent water body, wetland size and numbers of sport fish species present. But given knowledge available on freshwater fish ecology, it would seem that more sophisticated approaches are feasible and could be important aids in administration of wetland regulations.

Productivity

Primary productivity is used as a measure of the effectiveness of a wetland in converting solar energy to a form of energy that may be used to power biological processes which sustain life in general and give rise to many of the valuable functions of wetlands. Tidal saline marshes have long been recognized as among the most productive landscape units in the world. Much of the regulation of coastal wetlands has focused on the protection of those marsh communities that most effectively produce organic matter to fuel the biological processes of adjacent waters. Research during the 1970s suggests that freshwater tidal wetlands may be equally productive.[21]

The Virginia regulatory system[12] developed in the last decade, rates coastal plant communities according to their productivity and their location in the tidal flushing pattern. These ratings are used as guides for wetland regulation. Laws in other states often specify certain productive plant communities for prime protection. Measures of productivity may provide a general means to identify highly valuable wetlands,[18] but research is lacking on the productivity of many types of freshwater wetlands and on wetlands of the Pacific coast. Few productivity studies have included adequate knowledge of hydrology to document the movement of organic matter produced in the wetland and little is known about below-ground production. This role of wetlands is important to water quality and the production of valuable marine food resources, but those who administer wetlands have only the crudest means to take these values into account when considering permit applications.

Groundwater Supply

A widely held assumption is that freshwater wetlands generally recharge groundwater aquifers. Under some conditions, the groundwater system may receive some recharge from wetlands. However, wetland soils are typically less permeable than soils associated with groundwater-recharge areas, so recharge from wetlands will be less than from other areas. Most wetlands occur where water is discharging to the surface from the groundwater system (Figure 5).[22] In some cases, wetlands in the glaciated northeast are indicators of surficial geology that may contain high yield aquifers[23] for water supply wells that are more economical than surface water supplies.[9] Where this indicator role prevails, water on the wetland surface is usually not closely related to the water tapped by the wells.

Research in the past decade[23] has shown that wetlands are indicators of potentially high yield groundwater aquifers in Massachusetts, but further work is needed in other portions of the glaciated landscape, especially where organic soils are extensive. The relationship between wetlands and groundwater in the unglaciated landscape is still a matter for speculation and further research.

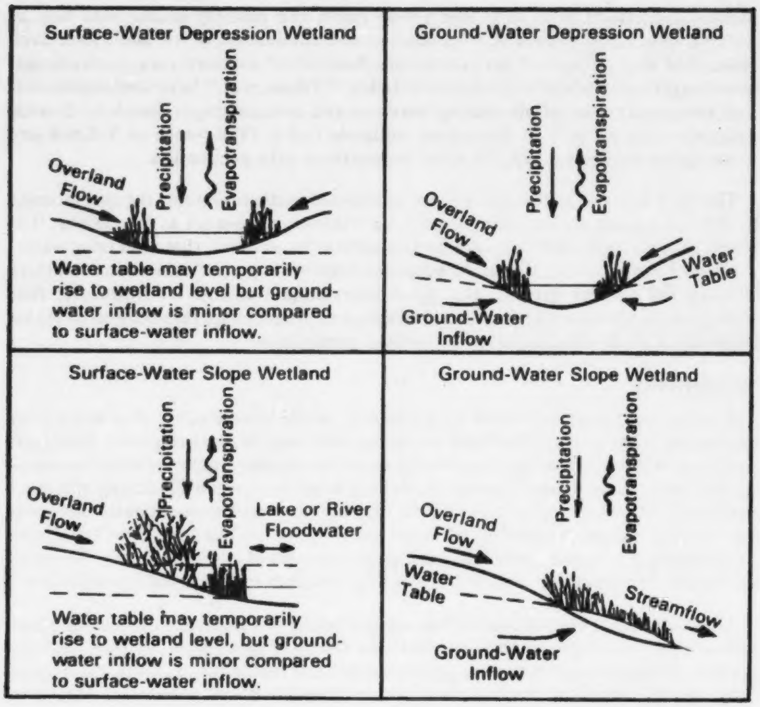

Surface-Water Depression Wetland
Precipitation
Evapotranspiration
Overland Flow
Water table may temporarily rise to wetland level but ground-water inflow is minor compared to surface-water inflow.
Ground-Water Depression Wetland
Precipitation
Evapotranspiration
Overland Flow
Water Table
Ground-Water Inflow
Surface-Water Slope Wetland
Precipitation
Evapotranspiration
Overland Flow
Lake or River Floodwater
Water table may temporarily rise to wetland level, but ground-water inflow is minor compared to surface-water inflow.
Ground-Water Slope Wetland
Precipitation
Evapotranspiration
Overland Flow
Water Table
Streamflow
Ground-Water Inflow

Figure 5. Basic hydrologic characteristics of wetland sites.[22]

Visual-Cultural

Visual-cultural or aesthetic values of wetlands arise from the fact that wetlands provide visual contrast and diversity on the landscape as well as various educational opportunities. Researchers in Massachusetts during the 1970s developed a system for ranking freshwater wetlands for comparative visual-cultural values.[24] They also developed economic values associated with this ranking, based on public willingness to pay for wetlands for aesthetic purposes.[9] The SCS[11] has employed a simple version of this system for use in their Massachusetts wetland evaluation scheme.

The concept of uniqueness of a wetland enters into some of the evaluation systems that were developed in the 1970s.[10,11,25] The proposition is that certain wetlands provide unique biological, geological, and historic conditions, or research potential that merit protection at all costs. It is usually suggested that relative ranking or economic evaluation of wetlands of this character is inappropriate. To be effective, systems that include this uniqueness factor need to employ characteristics for qualification that clearly distinguish such wetlands from other wetlands. Visual-cultural evaluation techniques are in need of more field testing to determine acceptance but few wetland regulatory programs consider this feature of wetlands.

Wildlife

The protection of wetlands as habitat for wild birds and mammals was the original purpose of public wetland acquisition programs. This function and various attempts to place economic values on wetland wildlife are well documented.[20,26] Early efforts at evaluation of wetland wildlife habitat centered on estimates of the dollar value of the wildlife product or of man days of recreational use. Current techniques focus on the habitat that produces the wildlife. A system of ranking freshwater wetlands for wildlife value, developed by Golet,[27] was based on biophysical characteristics of wetlands. Parallel economic values were derived from measures of public willingness to pay for purchase of wildlife wetlands.[9] The SCS has adapted this approach to their evaluation system in Massachusetts.[11] The U.S. Fish and Wildlife Service[28] is developing a Habitat Evaluation Procedure (HEP) applicable to wetlands and other aquatic and terrestrial sites. It is based on specific habitat needs of certain species of wildlife and generates a measure called habitat units. The procedure requires detailed information on the habitat requirements of a species and is applicable only to those species for which this information is available.

The HEP procedure is relatively untested and the Golet system was developed for northeastern conditions. Species specific and biophysical systems have different assumptions and strengths. Both need wider testing and comparison and the potential for integration of the two should be explored.

WHAT ARE THE IMPLICATIONS FOR FISH AND WILDLIFE?

Wetland wildlife habitat protection has emphasized purchase of wetland refuges by federal and state agencies. But wetlands purchase programs will never be sufficiently well financed to protect enough habitat from the modern stresses represented by dredging, filling and draining activities. As long as wetlands were viewed as having value only for wildlife, the prospects of maintaining an adequate network of wetland wildlife habitat were dim. Research of the last decade has identified health, safety and welfare values that stem from basic ecological functions of wetlands and these issues have attracted interest in and support for public management of wetlands to maintain these functions.

Along the coasts the interests of the fin fish and shellfish industry appear to generate sufficient public support for wetland regulation. Inland fish and wildlife values do not appear to generate, on their own, sufficient support for wetland regulation. Inland wildlife then becomes a beneficial spin-off value from wetland management for other socially and economically important reasons. Professional wildlife biologists, wildlife agencies, public and private and private persons concerned about wildlife will have to develop good understanding of other ecological functions of wetlands so that they can lend support for wetland management in the broadest context.

THE RESEARCH CHALLENGE FOR THE FUTURE

The greatest research need is the one that will be most effective in improving our understanding of how wetlands function and provide values to society. Water is the most important "forcing function" in wetlands. It is the ebb, flow and flushing of tides, the seasonal filling of potholes from snow melt and their draw-down by evaporation, and the periodic flooding of riverine wetlands that controls the production of vegetation, fish and wildlife habitat and biochemical functions of wetlands. Too few hydrologists are studying wetlands. Most are employed by the U.S. Forest Service and the U.S. Geological Survey. University studies of wetland hydrology are few and largely limited to southeastern and Gulf coastal wetlands.[29]

Much of what we know about wetland soils and their chemistry comes from research on how to drain them and use them for other than saturated or flooded conditions. Studies of flooded, anaerobic soil chemistry are difficult but necessary to understand when wetlands act as "sinks" or "exporters" of nutrients, wastes and heavy metals. Movement of water through organic muck and peat soils is poorly understood. We do not know if basic laws, useful to engineers working with dry soils, apply to wetland soils. But better information is needed to understand the function of wetlands as flood reservoirs, recharge and discharge sites and transporters of dissolved nutrients.

For all wetland functions we need to move from generalizations to specific site evaluations. Public agencies charged with administering wetland permit programs have to act on individual sites. Thus, they require the ability to determine how a particular wetland functions with regard to flood control, water quality and the like. Current procedures for evaluation of the flood control function are incomplete and the storm damage prevention role of wetlands has really not been field tested. Our understanding of the water quality function of wetlands needs to be refined for application on specific sites. The relationship of wetlands to groundwater in the south, central and western parts of the United States has not been studied to any degree. More work is needed to integrâte the general habitat and species specific approaches to wetland wildlife habitat evaluation.

Considerable effort is being made to develop economic measures of valuable functions of wetlands. In this process economists and ecologists have come in conflict. Perhaps the best example of conflict over the means by which dollar values are placed on wetlands is seen in the exchange of views that followed the publication of Gosselink, Odum and Pope's pamphlet on the value of the tidal marsh.[14] Resource **economists Shabman and Batie in Virginia challenged the validity of the Gosselink, *et al.* paper.[33] This critique was followed by no less than a rebuttal,[34] a replay to the rebuttal,[35] a short note by an invited critic[36] and a note of explanation from the editor** of the *Coastal Zone Management Journal.*[37] In short, economists say ecologists may not recognize the nature of the process by which economic values are determined. Ecologists, on the other hand, say that traditional economic processes fail to put a realistic value on functions of wetlands, such as their ability to transform solar energy into forms that support life on earth.

If wetland functions are to receive full appreciation in the coming decade, economists and ecologists must join research efforts and develop more widely accepted economic measures of wetland functions and values. If the conventional system of market place economics does not recognize that conversion of solar energy in natural ecosystems is essential for man's survival, quite possibly traditional economic evaluation techniques are not very helpful in making important decisions on how we manage wetlands or other ecosystems. On the other hand, public management is an expression of public desire. Dollar values are very effective in determining what policies the public will support, often with little regard to the findings of science. Clearly ecologists and economists, and the public, have much to gain from new research that will better attach dollar values to the flow of energy, water and nutrients in valuable wetland ecosystems.

Viewing the Nation as a whole, our knowledge of coastal wetlands is best on the south Atlantic and Gulf coasts. Our inland wetland information is best developed in the glaciated Northeast and the Great Lakes states. Elsewhere we have much less adequate Information. Scientific assessment of wetland ecological functions and values needs to be implemented on a regional basis to include all parts of the continental United States, Alaska and Hawaii. Some information can be transferred between regions but it is highly likely that wetlands that appear similar, function differently in different ecoregions. Ecologist Eugene Odum has pointed out that the importance of wetlands to man lies in the fact that they form the boundary between his living place, the land, and that essential life-support element, water. A decade of scientific research lends support to this observation and the coming decade must develop the tools to apply knowledge on a site-by-site basis.

REFERENCES

1. **Cowardin, L. M., V. Carter, F. C. Golet, and E. T. Laroe. 1979. Classification of wetlands and deep water habitats of the United States. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 103 pp.**

2. Kusler, J. A. 1978. Strengthening state wetland regulations. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 147 pp.
3. Greeson, P. E., J. R. Clark, and J. E. Clark. 1979. Wetland functions and values: the state of our understanding. Proc. Nat. Symp. on Wetlands, American Water Resources Assn. Minneapolis, Minn. x+674 pp.
4. Corps of Engineers. 1972. Charles River Massachusetts, appendices. New England Division, Dept. Army. Waltham, Mass. Variously paged.
5. Corps of Engineers. 1972. Charles River Massachusetts, main report and attachments. New England Divison, Dept. Army. Waltham, Mass. 68 pp. plus three plates and attachments.
6. Degen, J. 1971. Neponset River basin flood plain and wetland encroachment study. Div. Water Resources, Mass. Water Resources Commission, Boston, Mass. 56 pp. plus 27 exhibits.
7. Water Law Center. 1979. Model surface water runoff control ordinance. College of Law, Univ. of Florida, Gainesville, Fla. 33 pp.
8. Rockefeller, L. 1975. Why wetlands are natural protective barriers against flooding. Natural Resources Defense Council, Inc., New York, N.Y. Variously paged.
9. Gupta, T. R., and J. H. Foster. Economics of freshwater wetland preservation in Massachusetts. pp. 66-84 (*In* 25).
10. Reppert, R. T., W. Siglio, E. Stakhiv, L. Messman, and C. Meyers. 1979. Wetland values, concepts and methods for wetlands evaluation. Research Report 79-R1, U.S. Army Corps of Engineers, Institute for Water Resources, Belvoir, Va. 109 pp.
11. Soil Conservation Service. 1979. Water and related land resources of the Connecticut River Region, Massachusetts. U.S. Dept. Agriculture. Amherst, Mass. Variously paged.
12. Silberhorn, G. M., G. M. Dawes, and T. A. Barnard, Jr. 1974. Guidelines for activities affecting Virginia wetlands. Coastal Wetlands of Virginia Interim Report No. 3. Virginia Institute of Marine Science. Gloucester Point, Va. 52 pp.
13. Tilton, D. L., R. H. Kadlec, and B. R. Schwegler. 1978. Phase II, The ecology and values of Michigan's coastal wetlands. 98 pp. *In* Coastal wetlands value study, Phase I and II, Michigan Dept. of Natural Resources. Lansing, Mich. 329 pp.
14. Gosselink, J. G., E. P. Odum, and R. M. Pope. 1974. The value of the tidal marsh. Pub. No. LSU-SG-/4-03. Center for Wetland Resources. Louisiana St. Univ., Baton Rouge, La. 30 pp.
15. Sloey, W. E., F. L. Spangler, and C. W. Fetler, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. pp. 321-340. *In* Freshwater wetlands ecological processes and management potential., R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Academic Press, New York, N.Y. 378 pp.
16. Wharton, C. H., H. T. Odum, K. Evel, M. Duever, A. Lugo, R. Boyt, J. Bartholomew, E. DeBellevue, S. Brown, M. Brown, and L. Duever. 1977. Forested wetlands of Florida, their management and use. Center for Wetlands. Univ. of Florida, Gainesville, Fla. 348 pp.
17. Kadlec, R. H. 1979. Wetland utilization for management of community wastewater. Wetland Ecosystem Research Group. Univ. of Michigan, Ann Arbor, Mich. 103 pp.
18. Kibby, H. V. 1978. Effects of wetlands on water quality. pp. 289-298. *In* Proceedings of the Symposium on Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Pub. GTR-WO-12, U.S. Dept. Agric. Forest Service. Washington, D.C. 410 pp.
19. McHugh, J. L. 1976. Estuarine fisheries: are they doomed? pp. 15-27. *In* Estuarine Processes, Vol. I. Use, stresses and adaptation to the estuary. M. Wiley, ed. Academic Press. New York, N.Y. 541 pp.

20. Jaworski, E., and C. N. Raphael. 1978. Fish, wildlife and recreational values of Michigan's coastal wetlands. Dept. Geography and Geology, Eastern Michigan Univ., Ypsilanti, Mich. 209 pp.

21. Whigham, D. F., J. McCormick, R. E. Good, and R. L. Simpson. 1978. Biomass and primary production in freshwater tidal wetlands of the Middle Atlantic coast. pp. 3-20. *In* Freshwater wetlands, ecological processes and management potential. R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Academic Press. New York, N.Y. 378 pp.

22. Novitzski, R. P. 1979. An introduction to Wisconsin wetlands, plants, hydrology and soils. Univ. of Wisconsin-Extension, Geological and Natural History Survey. Madison, Wisc. 19 pp.

23. Heeley, R. W., and W. S. Motts. A model for the evaluation of groundwater resources associated with wetlands. pp. 52-65 (*In* 25).

24. Smardon, R. C., and J. Gy. Fabos. Visual-cultural sub-model. pp. 35-51 (*In* 25).

25. Larson, Joseph S., ed. 1976. Models for assessment of freshwater wetlands. Pub. No. 32, Water Resources Research Center, Univ. of Mass., Amherst, Mass. 91 pp.

26. Leitch, J. A., and D. F. Scott. 1977. A selected annotated bibliography of economic values of fish and wildlife and their habitats. Dept. of Agric. Econ., N. Dakota State Univ., Fargo, N. Dakota. 132 pp.

27. Golet, F. C. Wildlife wetland evaluation model. pp. 13-34 (*In* 25).

28. Schamberger, M. L., C. Short, and A. Farmer. 1979. Evaluation of wetlands as wildlife habitat. pp. 74-83. *In* Wetland functions and values: The state of our understanding. P.E. Greeson, J. R. Clark, and J. E. Clark, eds. Amer. Water Resources Assn. Minneapolis, Minn. 674 pp.

29. Larson, J. S., and O. L. Loucks. 1978. Workshop report on research priorities for wetlands ecosystem analysis. Report to the National Science Foundation by the National Wetlands Technical Council (c/o The Conservation Foundation). Washington, D.C. 68 pp.

30. Gosselink, J. G., and R. E. Turner. 1978. The role of hydrology in freshwater ecosystems. pp. 63-78. *In* Freshwater wetlands, ecological processes and management potential. R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Academic Press. New York, N.Y. 378 pp.

31. Odum, E. P. 1978. The value of wetlands: A hierarchical approach. pp. 16-25. *In* Wetland functions and values: The state of our understanding. P. E. Greeson, J. R. Clark, and J. E. Clark, eds. American Water Resources Assn. Minneapolis, Minn. 674 pp.

32. Prentki, R. T., T. D. Gustafson, and M. S. Adams. 1978. Nutrient movements in lakeshore marshes. pp. 169-194. (*In* 30).

33. Shabman, L. A., and S. S. Batie. 1978. Economic value of natural coastal wetlands: a critique. Coastal Zone Management Journal. 4 (3): 231-247.

34. Odum, E. P. 1979. Rebuttal of "Economic value of natural coastal wetlands: a critique." Coastal Zone Management Journal. 5 (3): 243-244.

35. Shabman, L. A., and S. S. Batie. 1979. A reply to the rebuttal of "Economic value of natural coastline wetlands: a critique." Coastal Zone Management Journal. 5(3): 239-241.

36. Odum, H. T. 1979. Principle of environmental energy matching for estimating potential economic value, a rebuttal. Coastal Zone Management Journal. 5 (3): 239-241.

37. M.J.H. 1979. Editors note on the comments from Eugene P. Odum, Howard T. Odum, Leonard Shabman, and Sandra Batie. Coastal Zone Management Journal. 5 (3): 257-258.

INSTREAM FLOW ASSESSMENTS COME OF AGE IN THE DECADE OF THE 1970s

Clair B. Stalnaker

INTRODUCTION

Historically, water rights could be obtained in the western United States only through a state appropriation for applying the water out of the stream to some "beneficial" use. Beneficial use has been defined by state law and normally has included municipal, industrial, stock watering, agricultural, and mining. Stream and associated riparian ecosystems, recreation, and aesthetics have only recently been recognized as beneficial uses of water in some states. These water uses and several others which depend on in-channel flow are often referred to as "instream uses," and their flow requirements as "instream flow needs."

In the face of increasing water demands for energy and expanded agricultural production, there has been a widespread recognition of the necessity for maintaining water in the stream for such uses as fish and wildlife production, recreation and aesthetic enjoyment, estuarine inflows, hydropower, and navigation. Recent legislation and court decisions have pointed out the need for identifying instream flow requirements and quantifying their magnitude. With legal recognition that instream uses should be considered on a par with offstream uses came increased demand for methodologies to supply water resource agencies and planners with information to: (1) determine relationships between benefits derived from instream uses and streamflow quantity; and (2) determine the optimum allocation of limited fresh water resources among various instream and offstream uses.

During the past three decades, federal and state agencies involved with water resource use and management have independently been devising methodologies in an attempt to address these problems. This resulted in much duplication of effort, fragmented approaches, and considerable lag in acceptance of credible methods. However, substantial progress for protecting instream habitat for fish and wildlife was achieved during the decade of the 1970s due to two primary reasons:

1. New environmental legislation emerged as a result of a heightened awareness by the public of the growing reduction of our stream ecosystems and the realization that only through legal protection would future generations be able to enjoy these instream values.
2. Stimulated by demands from the water planning community for quantitative documentation of instream flow requirements, new techniques were devised that produced persuasive support for the aquatic biologist's recommendations.

This paper traces the evolution of instream flow assessment methodologies and highlights the legal and institutional events which contributed to the increased interest

---

The Author: Dr. Stalnaker currently serves as Leader, Instream Flow and Aquatic Systems Group, Western Energy and Land Use Team, Fish and Wildlife Service, U.S. Department of the Interior, Fort Collins, Colorado. His professional background also includes applied research in the state of West Virginia natural resources, the FWS Cooperative Fisheries Research Unit, Utah State University, Logan, and Fishery Research Specialist, Federal Aid Program, Denver, Colorado.

in instream uses of water. The midsection of the paper will concentrate on the hydraulic based microhabitat approaches presently in vogue. Finally, it will offer research needs which should advance the state-of-the-art and chart a course for continued progress during the 1980s and beyond.

EARLY EFFORTS

Prior to the 1970s the consideration of the instream values of water in the water administration arena was inconsistent, frustrating, and confusing at best. The first documented instream flow study for water planning purposes was conducted in Colorado on the Colorado River below the Granby Dam site in the late 1940s by Ralph Schmidt of the U.S. Fish and Wildlife Service. Although this study had little influence on the construction agency, it employed concepts which are still being applied today.

Biologists have been attempting for 30 years to integrate protection for streamflows for fish and wildlife resources into the planning efforts of federal water development agencies. The relative success of these efforts depended upon such factors as existing state law, personal salesmanship in presenting the recommendations, but probably most of all, on the prevailing philosophy of the construction agencies and the politicians in control. In the eastern states, the philosophy reflected the existence of riparian doctrine and few streams were totally diverted, although many did suffer adverse effects. In the western states where an appropriation doctrine prevailed, the philosophy of protecting instream values simply did not compete with the frontier ethic of conquering the wilderness and harnessing the natural resources for economic gain. This philosophy was evident in the water development planning for the Bureau of Reclamation, Corps of Engineers, and State Water Development Agencies. When some measure of protection was afforded to instream values, it was more a matter of allocating dam leakage or water excess to project need for instream values than a matter of attempting to sincerely protect the fluvial ecosystem. The result was that stream-flows became depleted from 40 to 100 percent in many western rivers as the decade of the 70s arrived.

No state had adequate legislation on the books to purposefully protect instream values. In Oregon there was a policy of recognizing instream values and supposedly protecting sufficient flow to sustain fisheries. As the drought of 1977 later revealed, this policy fell short of adequate legal protection.

The methodologies for determining instream flow needs before 1970 were limited to several approaches developed by individual biologists which relied heavily on professional judgment. Ironically, it was this reliance on professional judgment that seemed to be largely responsible for the failure to get recommendations accepted. The state engineers and water policy boards were trained to deal with quantified data. Even if inclined to protect instream values, most state engineers were reluctant to make decisions solely on the judgment of a biologist.

During the 1950s and 1960s the water planning community began to recognize that instream flow needs were a legitimate part of water administration. This largely came about as a result of the Fish and Wildlife Coordination Act and its amendments through 1958. However, investigations into instream flow requirements for fisheries and maintenance of the aquatic ecosystem was inappropriately viewed as only a part-time job. Such work was conducted by biologists in various state and federal agencies, working independently and using a variety of methods.

The major impetus to instream flow assessments came as a spinoff of the Water Resource Planning Act of 1965 which established the Water Resources Council and authorized regional river basin commissions.

Through the Water Resources Council and the regional river basins, a new program of comprehensive, coordinated interdisciplinary planning by representatives of a wide variety of agencies was begun. It was through such efforts, most notably in the Pacific Northwest, where salmon and steelhead runs were recognized as having high economic values, that support began to grow outside the fish and wildlife agencies for more fairly considering the best way of providing for instream flows in long-range water planning. The biologist participating on these interagency planning teams argued for including adequate protection for sufficient streamflow to protect the fish and wildlife habitats as equal elements in these comprehensive plans.

The first national recognition of a need for qualifying "that amount of flow sufficient to support those values of naturally flowing streams held in high esteem by man" was reported in the 1968 National Water Assessment,[1] which stated that "lack of comparable data (to those provided for offstream uses) on instream uses has prevented meaningful analyses and comparisons." Thus began an era of comprehensive coordinated planning which provided a forum for elevating instream values to the status of legitimate functional uses of the nation's waters.

Institutional Awareness

The institutional awareness opened the decade of the 1970s when, on January 1, President Nixon signed into law the National Environmental Policy Act of 1969. This act required environmental policy statements to be prepared and distributed publicly describing the environmental effects of any significant federal action or action requiring a federal permit.

April 22, 1970, was the first Earth Day. This nationally celebrated citizens' movement is credited as the beginning of an awareness by the average citizen for a need to protect environmental values. Other legislation was passed during the early 1970s which provided additional impetus to this growing recognition of a need to do business differently in the water planning sector.

Figure 1 presents a chronology of the important legal and institutional events contributing to the increased interest in instream flow needs. Several significant studies grew out of the emerging legislation and institutional attempts to cope with this "new" water use identity. Stimulated by the continued insistence of the water planners for quantified expressions of instream flow needs, biologists of the state and federal fish and wildlife agencies began earnestly examining the available techniques and the need for improvement. The first collective action resulted in the proceedings of a conference held in Portland, Oregon, in March 1972. This meeting was organized by field personnel of the U.S. Fish and Wildlife Service and sponsored by the Pacific Northwest Commission; it was attended by over a hundred biologists and water resources planners. The participants heard of the techniques then in practice by the Oregon Wildlife Commission, U.S. Forest Service in Utah, and state and federal biologists from Montana.

In 1971, the Washington State Legislature had passed legislation calling for the establishment of base flows in all rivers in the state to protect instream values, particularly the anadromous fishery resource. This mandate stimulated the new Department of Ecology in the State of Washington to sponsor a second conference that fall. In November 1972, knowledge-thirsty planners and biologists assembled again in Olympia, Washington, to hear from additional speakers who had struggled with the process of quantifying instream flow requirements. Notable among the papers presented was the work of Collings, et al., who described spawning requirements of salmon in Washington's coastal streams and the work of recreation planners, who attempted to describe the stream flow requirements of this highly recognized public resource. In the months that followed there were numerous field studies conducted by biologists from a variety of agencies. The resulting recommendations began to find their way into the comprehensive planning meetings being pursued throughout the western states. While these studies did not implement the recommendations, they did provide visibility to the arguments for protecting instream flows and the limitations in the available methodologies for allowing the analysis of increments of change in stream flow.

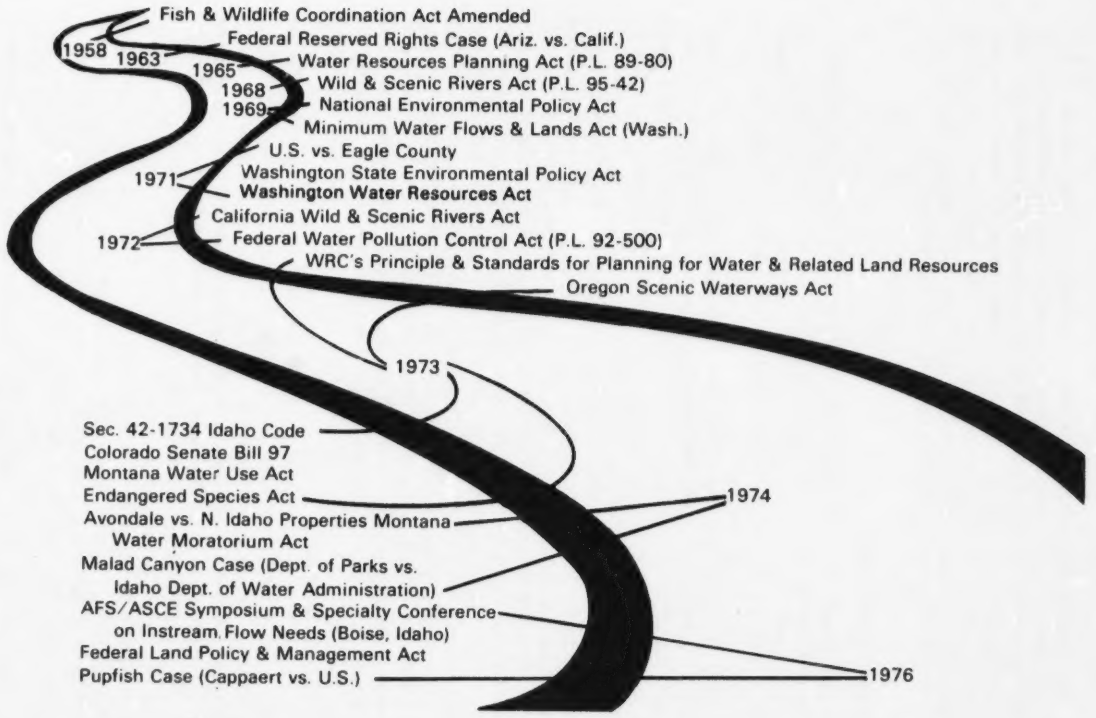

Fish & Wildlife Coordination Act Amended
1958
1963
Federal Reserved Rights Case (Ariz. vs. Calif.)
1965
Water Resources Planning Act (P.L. 89-80)
1968
Wild & Scenic Rivers Act (P.L. 95-42)
1969
National Environmental Policy Act
Minimum Water Flows & Lands Act (Wash.)
U.S. vs. Eagle County
1971
Washington State Environmental Policy Act
Washington Water Resources Act
California Wild & Scenic Rivers Act
1972
Federal Water Pollution Control Act (P.L. 92-500)
WRC's Principle & Standards for Planning for Water & Related Land Resources
Oregon Scenic Waterways Act
1973
Sec. 42-1734 Idaho Code
Colorado Senate Bill 97
Montana Water Use Act
Endangered Species Act
1974
Avondale vs. N. Idaho Properties Montana Water Moratorium Act
Malad Canyon Case (Dept. of Parks vs. Idaho Dept. of Water Administration)
AFS/ASCE Symposium & Specialty Conference on Instream Flow Needs (Boise, Idaho)
Federal Land Policy & Management Act
Pupfish Case (Cappaert vs. U.S.)
1976

Figure 1. Legal and institutional events which contributed to increased interest in instream flow assessments.

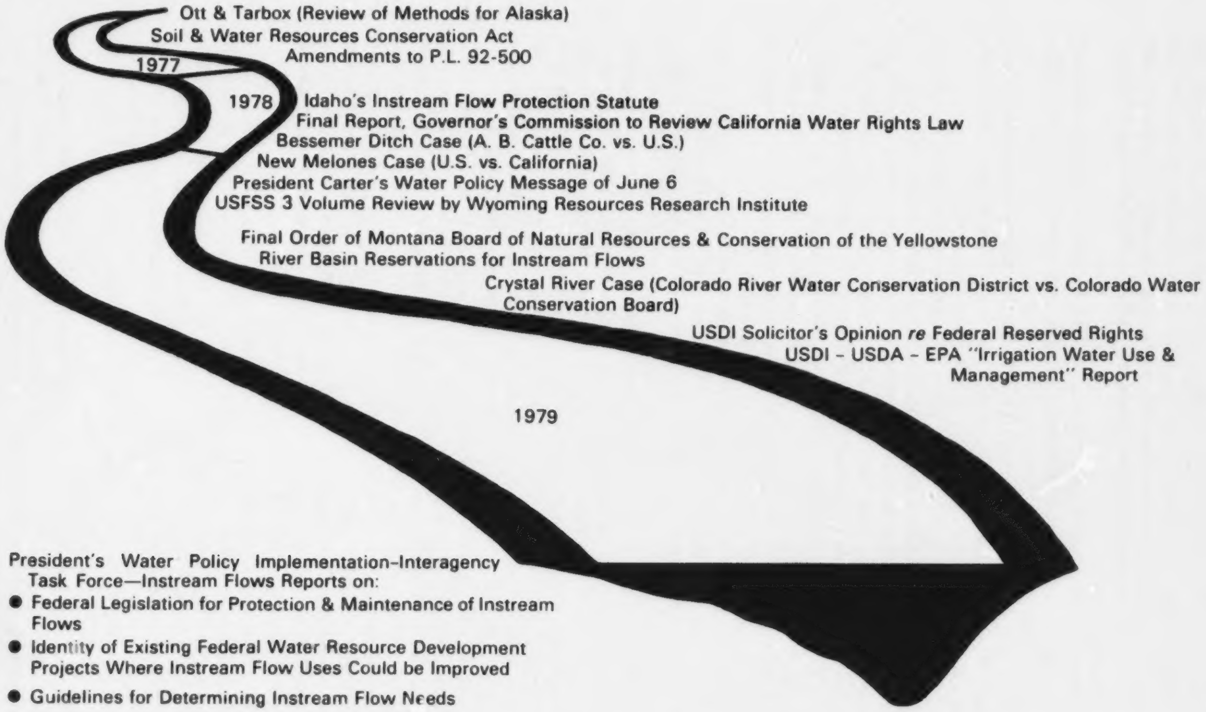

Ott & Tarbox (Review of Methods for Alaska)
Soil & Water Resources Conservation Act
1977
Amendments to P.L. 92-500
1978
Idaho's Instream Flow Protection Statute
Final Report, Governor's Commission to Review California Water Rights Law
Bessemer Ditch Case (A. B. Cattle Co. vs. U.S.)
New Melones Case (U.S. vs. California)
President Carter's Water Policy Message of June 6
USFSS 3 Volume Review by Wyoming Resources Research Institute
Final Order of Montana Board of Natural Resources & Conservation of the Yellowstone River Basin Reservations for Instream Flows
Crystal River Case (Colorado River Water Conservation District vs. Colorado Water Conservation Board)
USDI Solicitor's Opinion re Federal Reserved Rights
USDI - USDA - EPA "Irrigation Water Use & Management" Report
1979
President's Water Policy Implementation–Interagency Task Force—Instream Flows Reports on:
● Federal Legislation for Protection & Maintenance of Instream Flows
● Identity of Existing Federal Water Resource Development Projects Where Instream Flow Uses Could be Improved
● Guidelines for Determining Instream Flow Needs

Figure 1. (Continued)

The following reports have shaped regional and national policy during the 1970s:

1. River basin commission reports:
    a. The 1972 "Columbia-North Pacific Region Comprehensive Framework Study" of the Pacific Northwest River Basins Commission emphasized the need for instream flow data as a prerequisite to planning, and placed a high priority on studying legal and administrative means for enforcing minimum streamflows, and
    b. The 1975 "Annual Report of the Missouri River Basin Commission" identified the determination of instream flow requirements as a high priority study.
2. The Department of the Interior's 1974 "Westwide Study Report on Critical Water Problems Facing the Eleven Western States" found that a major data gap existed in the area of instream flow needs determination.
3. In 1974, an *ad hoc* instream flow study evaluation committee of the Pacific Northwest River Basin Commission identified critical needs including: the development of low-cost methodologies, evaluation of impacts, benefits for increments of flow, and improvement of existing legal and institutional systems for controlling instream flows of inter- and intra-state waters.
4. A 1975 "Regional Problem Analysis" conducted by the Water Resources Research Institutes of Washington, Oregon, and Idaho stressed the need for improved mechanisms for coordination between state and federal agencies to determine instream flow needs and effect their enforcement.
5. A FWS Western Water Allocation project-sponsored study and workshop conducted at Utah State University in 1975 evaluated the methodologies in use for determining stream resource maintenance flow requirements and pointed out numerous deficiencies in the state-of-the-art and in understanding discharge-aquatic ecosystem relationships. The published report recognized that methodologies are needed to directly assess the magnitude and range of effects resulting from a series of changes in discharge through a stream channel. It went on to say that "for rational water resource planning, these effects must be predicted and described for incremental decreases or increases of flow. The more fully documented options the planners and decisionmakers have available, the more rational and equitable the ultimate decisions."[2]
6. A national instream flow needs symposium and specialty conference, jointly sponsored by the Western Division of the American Fisheries Society and the Power Division of the American Society of Civil Engineers, was held in Boise, Idaho, in May 1976. This conference provided an open forum and published proceedings for the discussion of the major single and multi-disciplinary problems associated with the allocation of streamflow among competing uses and the short- and long-term effects of such allocations on the values of streams. It also sought solutions to technical, legal, and social problems caused by increasing competition for limited streamflow.[3]
7. The critical need for a coordinated, substantive effort to provide a focus for the multitude of divergent ongoing efforts concerning instream flow assessments was documented in a proposal by the U.S. Fish and Wildlife Service, Division of Ecological Services, in a document entitled "Toward a National Program of Substantive Instream Flow Studies and a Legal Strategy for Implementing the Recommendations of Such Studies." Subsequently, the Office of Biological Services, FWS, established in 1976 the Cooperative Instream Flow Service Group (IFG) in Fort Collins, Colorado.
8. The U.S. Water Resources Council launched a second national water assessment during 1974. This assessment gave substantial opportunity to increase the visibility of concern for instream values. While the assessment was not released until near the end of the decade, the discussions and circulation of early drafts of working papers and appendices had the effect of broadening the

circle of natural resources planners who were aware of the critical need for improved information.

9. The President's water policy initiatives of June 1978 included water conservation and protection of the environment by "directing all Federal agencies to incorporate water conservation requirements in all applicable programs. . .and by requiring agencies to fund environmental mitigation plans at the same time projects are being built."

Methods Development

In addressing an instream flow problem, the fishery manager is often confronted with three sequential questions:

1. How much water is needed to maintain the fishery?
2. What happens if that much water (or a particular release schedule) cannot be provided?
3. How many fish are gained or lost with different levels of streamflow in the river?

A plethora of various methods has been devised to answer the first question. Where conflicts over a supply of water are minimal, any of these methods may be used with satisfactory results. However, as in the case of any resource in short supply, conflicts regarding the allocation and use of water are the rule rather than the exception. Therefore, the second question is frequently asked almost in the same breath as the first one. Methods designed to determine a "minimum flow requirement" have been found to be insufficient to address the question of incremental effects of changes in discharge.

Most all instream flow assessment methods in use during the 1970s fall into either the rule-of-thumb (hydrologic based) or the physical habitat (hydraulic based) categories. These have been reviewed in depth elsewhere.[2,3,4] The following summary appears useful to denote the principal difference between the two categories (see references 5 and 6 for similar discussions).

The need for rule-of-thumb procedures came from the water planning and water administration professions which are used to deal with good historical data bases of streamflow and watershed (catchment basin) runoff records. Such methods based upon specified percentages of average annual conditions gave rise to the "minimum" flow concept for allocating water among offstream and instream uses. These methods are useful when evaluating water availability on an annual basis for planning purposes or granting of water rights under legislative processes. Most fishery administrators do not approve of the use of rule-of-thumb derived "minimum" flows for fishery maintenance when a stream is regulated (controlled by dams or diversion).[7,8] That is to say that the "operating rules" by which water is managed must recognize the dynamic nature of the flow regime present in stream systems and cannot be reduced to a single fixed flow value.

This discontent with the rule-of-thumb approach seems to stem from the hydrologist-engineers' perspective that the fishery does not require all of the streamflow during any time other than infrequent drought conditions.[8] This perspective has led to the unfortunate use by planners of such historic low flow values as: the 7-day Q_{10} (the lowest flow occurring for 7 consecutive days once in 10 years), the 90% exceedence flow, 10% of mean annual discharge, and even the lowest flow of record, as the selected minimum flow for instream protection. Such schemes fail to recognize that the fishery is a dynamic resource which can tolerate extreme drought conditions on infrequent occasions but cannot tolerate these low flows on a sustained basis without extreme reductions in the production and yield of the fishery.

Tessman[9] adequately summarized this concern when he stated "the best minimum flow model is one that mimics nature. . . The year is a continuum of cyclic events to which the natural community is adapted. Minimum flow expressed as total volume of instream requirements during the course of a year is meaningless unless streamflow is distributed properly during this period."

For the purpose of water planning and interim determinations of the availability of water for future development, the median or average monthly flow values are accepted as more representative of the flow necessary to maintain a healthy fishery resource.[6] In such analyses, flows in the "optimum" or "acceptable" range are much less controversial among fishery managers and ecologists. Following are examples of rule-of-thumb approaches used in reconnaissance level evaluations of water resources:[5]

- Median monthly flow values equal to 79-100% of the average flow for each month of record.
- Monthly minimum flows equal to the mean monthly flow (MMF) if MMF<40% of mean annual flow (MAF). If MMF>40% MAF, monthly minimum flows equal 40% MAF. If 40% MMF>40% MAF, monthly minimum flows equal 40% MAF.
- Single values of 60-100% of mean annual flow or 70-130% of the natural characteristic low or base flow.

Most applications of these methods to early-planning now recognize that flood flows are also needed to cleanse the substrate and otherwise maintain the physical integrity of the stream channel. Bankfull flows are generally now recognized as necessary for maintaining channel cross-sectional integrity. However, the frequency and duration of these flows are the basis of much argument.

Physical Habitat Analysis

Many researchers have documented the preference of stream fishes for particular ranges of depths, velocities, substrate size, cover objects,[10,11,12,13,14] and temperature.[15,16] Nearly all site specific methods proposed to date are based upon measurement of these important stream variables.

All physical habitat-flow analyses can be further grouped in two categories: (1) those based upon threshold conditions at critical or limiting macrohabitat features, and (2) those based upon microhabitat features within specified (sometimes called representative) stream reaches.

Threshold methods. The methods require that species criteria for depth, velocity, and substrate be specified. These criteria usually take the binary form with a specified range. (See Stalnaker and Arnette,[2] and Wesche and Rechard[4] for summaries of reported criteria.) The other necessary step is the measurement of depth, velocity, and substrate along transects placed over the stream channel. When measured at several different discharges, the "usable width" across the measured transect can be computed. Variations on this approach are described elsewhere.[2,4] Another method which has often been used is the measurement of wetted perimeter at several discharges. A plot of wetted perimeter vs. discharge is then produced. Such visual methods rely upon either a peak or obvious inflection point on the curves which is stipulated as the discharge which maximizes the "usable habitat" (i.e., the upper threshold) in the stream channel studied.

Arbitrary calculations for establishing the "minimum" threshold conditions have been suggested such as: (1) 75-90% of the maximum or optimum value; (2) the value at which a tangent, drawn through the origin of the graph, touches the curve; and (3) the discharge which produces the maximum contiguous width along a transect having some specified depth value. The "minimum" threshold values have no documented biological basis and are the subject of much controversy among ecologists. These threshold methods do not take into consideration the timing of flow in the stream channel and, therefore, should be restricted to regulated stream applications when storage in large reservoirs makes possible releases downstream for maximizing fishery habitat conditions.

Microhabitat methods. These methods differ from the threshold methods above in that the species criteria are often weighted and a stream reach is described in terms of the spatial distribution of the hydraulic parameters of depth and velocity over suitable substrate. The areal extent of suitable habitat vs. discharge is easily determined for several different discharges. Maximum area of suitable habitat vs. discharge is also easily determined from these analyses, but any selection of minimum levels of flow is quite subjective.

Fishery scientists in the Pacific Northwest developed an approach which uses a series of overlay maps, delineating areas where the depth, velocity, and substrate are within the preferred ranges for spawning salmon. The ranges for these criteria are termed "binary" criteria, where the utility of a variable takes on the integer value of zero, or one, depending on whether or not it falls within the preferred range of the animal. Areas of intersection of all three preferred ranges are identified and measured by planimeter. This procedure is repeated for a range of discharges, and a plot of discharge vs. preferred spawning is developed.[17] The U.S. Geological Survey, Tacoma, Washington, has developed a computer program (DVA TRAPESIARRAY) used in producing these plots for the Washington Department of Fisheries and Game. Although time consuming, the method is straightforward and fairly simple in design (necessary attributes for presentation to water administrators). Since calculations are based upon empirical field data and are graphical in nature, the results of the method are easily understood.

A refinement in the early 1970s was an outgrowth of work initiated by the California Department of Fish and Game. The basic concept is the same except that they substituted for binary criteria, weighting factors which ranged from zero to one, to represent the relative habitat values of the three stream attributes to obtain an equivalent "optimum quality streambed area."[18] These weighting factors could be varied as a function of species, life stage, or principal food organisms. They could be estimated for many species from information available in the literature and from professional judgment; but for some species, this information could be obtained only from new research.

The principal drawback to the physical habitat methodologies was the intensive labor needed to acquire hydraulic information from the stream. During 1976, several researchers reported upon the use of hydraulic modeling techniques to simulate hydraulic conditions at unobserved discharges and minimize time in the field.[19,20,21,22,23] However, at that time the use of hydraulic simulation modeling for habitat analysis was in its infancy and simply a "spinoff" of flood routing models. The hydraulic models available could best be described as macrohabitat models, giving output in terms of depth, mean velocity, and wetted perimeter at a cross section. As such, the models were not precise enough for the in-depth microhabitat quantification practiced in the Pacific Northwest and California and most were used for threshold analysis only.

THE INSTREAM FLOW INCREMENTAL METHODOLOGY

During 1977 and 1978, the Cooperative Instream Flow Service Group (IFG) in Fort Collins, Colorado, took on a major role of synthesis, documentation, and refinement of training relating to physical habitat analyses. This effort was set first in a hierarchical framework of macro- and micro-stream habitat considerations. Secondly, it utilized a modular approach upon which to focus and set the boundaries of the problem studied. Finally, the progression from initial planning to system management and operation was used to identify the level of precision which, along with the level of measured or simulated detail, determined the degree of sophistication of analysis along levels compatible to the level A, B and C studies described by the Water Resources Council.[6,24] Since this methodology is generally accepted as the state-of-the-art site specific, or Level C approach, it is discussed in some detail below.

Macro- vs. Microhabitat

Let us first differentiate between macro- and microhabitat features by examining a river from its headwaters to its mouth. Numerous authors have reported the addition or replacement of species as a function of stream order, stream size, gradient, or other descriptions of longitudinal gradations on environmental considerations.[25] An initial viewpoint relates the "longitudinal succession" of species as a function of such variables as mean depth, temperature, mean velocity, water quality, average substrate composition, or other environmental conditions which exhibit gradational change. These are the macro-features of the stream habitat.

A second perspective is to examine local preference or response in regard to the morphological, physiological, or behavioral adaptions of various species. Many studies have shown that the spatial and temporal selection of certain microhabitat conditions reduces interspecific competition.[26,27,28] In fact, expansion into another species' preferred microhabitat in the absence of that species (competitive release) occurs less frequently in streams than one would expect.

The geographic distribution of species in riverine systems is largely dictated by those longitudinal characteristics which define the macrohabitat. In essence, the characteristics of watershed and water quality establish the limits of distribution of a species. These bounds are often discontinuous—subject to inversions in macrohabitat gradients.

If the macrohabitat conditions are sufficient for the growth and propagation of fish, the distribution and abundance of fish within the macrohabitat is a function of the availability of proper microhabitat conditions. A microhabitat is then perceived as a necessary subset of the macrohabitat. A macrohabitat might be adequate for fishes to exist, but without the necessary microhabitat fish abundance will be limited. The converse is also true. Therefore, the quantification of habitats must concern both the longitudinal (macrohabitat) distribution of species and the three-dimensional (microhabitat) distribution within the macrohabitat.

Gorman and Karr[29] concluded that four variables were significant in determining the distribution and abundance of species in a river system. These are energy source (watershed inputs), water quality, channel structure, and flow regime. From the above discussion it can be argued that certain variables such as energy source and water quality change longitudinally through a system and could logically be defined as macrohabitat features. Channel structure and flow characteristics (hydraulic structure) together determine the microhabitat, but these too change longitudinally through the system.

The approach taken by the IFG is to superimpose detailed microhabitat characteristics onto more generally described, relatively homogeneous macrohabitat based on changes in watershed characteristics, water quality, overall channel geometry, and flow regime. Thus, a river system may be segmented into sections in which the macrohabitat conditions are relatively homogeneous. Macrohabitat gradations are illustrated by proceeding from one river segment to the next.

Within each of these large, relatively homogeneous segments, small reaches are randomly selected for detailed study of the relationship between microhabitat and streamflow. Such reaches are called *representative reaches*. Variations in microhabitat, as determined by channel structure and streamflow, are described over the length of macrohabitat as represented by these sample reaches. This approach allows an investigator to describe not only the microhabitat conditions, but also how microhabitat intergrades with macrohabitat throughout the entire river system. Therefore, both the longitudinal succession perspective and the microhabitat selection perspective of riverine ecology are incorporated in the approach.

Modules for Analysis

Starting with an incremental water allocation perspective, the IFG approach to developing an analytical procedure sensitive to both macro- and microhabitat quantification recognized that:

1. Physical processes drive biological processes, i.e., biological species evolve (respond) to fill niches in the physical habitat.
2. There are four components that are interrelated and must be evaluated:
    a. Watershed
    b. Water quality
    c. Channel structure
    d. Flow regime

Consistent with a philosophy of incrementalism (the examination of alternatives), it is necessary to first determine the characteristics of each of the components, determine the relationship among components, and be able to carry a change in one of the components through the entire system. This process should then allow the evaluation of the consequences of a small change anywhere in the system.

Such an approach starts with a hierarchical and modular setting. Figure 2 diagrams a structured thought process with a series of decision points, feedback loops, and cross-checking procedures needed to examine the component modules. The modules and state-of-the-art models constitute the "building blocks" of this procedure.

Watershed. The nature of the watershed governs the delivery of water to the stream, which in turn governs the nature of the flow regime and the size and shape of the channel. The decomposition of parent materials and input of allochthonous organic material determines the nutrient input to the stream, and its influence within the watershed by longitudinal changes in elevation, vegetation, geology, and climate. The substrate characteristics of a stream are dominated by the parent material present at various points along the longitudinal profile, i.e., streams flowing through resistant igneous or metamorphic parent materials tend to be coarse-bedded.

It would be convenient if longitudinal changes in watershed characteristics proceeded in a regular manner. Although many watersheds do exhibit smooth gradations, many others are typified by abrupt changes and occasionally by inversions. Consistent with the macrohabitat concept, the fauna of these streams also reflect these abrupt changes.

Most riverine habitat evaluation techniques presented earlier automatically assume that the conditions of the watershed are held constant. This assumption is often made as a convenience; it is easier to assume the problem away than to attempt to predict changes to the system imparted by the watershed. Where land use changes are not anticipated, climatic and geologic factors can be safely assumed as constant, and consequently a steady state watershed is a safe assumption. Conversely, a steady state assumption in an altered watershed would be totally inappropriate.

In an undisturbed watershed, both the terrestrial and aquatic environments are in a dynamic equilibrium. Perturbations on the watershed such as timbering, agriculture, grazing, mining, and urban development may drastically change the input rates to the stream system. Such watershed activities affect the stream system in three major ways: (1) through variations in water quantity input (either ground water or surface runoff) which affect the streamflow regime and in turn the physical structure of the channel; (2) through changes in heat, sediment, inorganic nutrients, and toxicants which all affect water quality and thus, the physiological responses of target organisms; and (3) through changes in the quantity of organic substances which influence the source of energy for utilization within the food web.

The initial question to be answered in this module is whether the watershed is in equilibrium with its drainage system, or whether it is changing. For a great many watersheds the question of watershed equilibrium can be answered with a simple

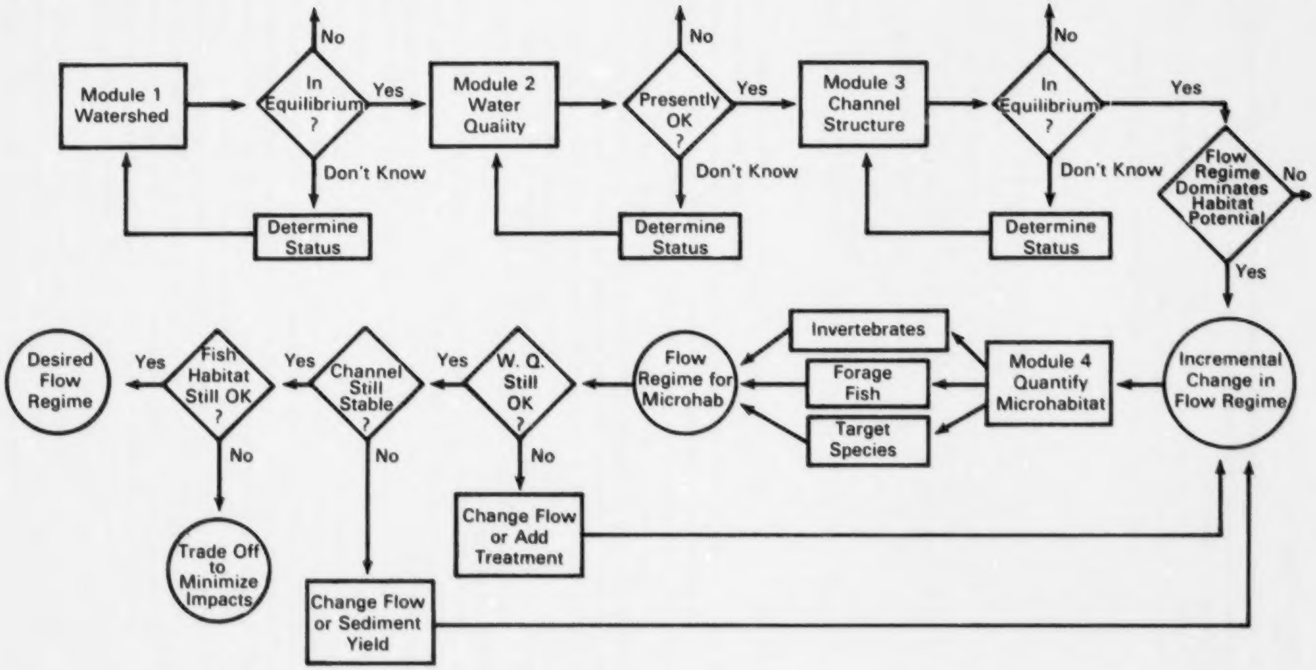


Figure 2. Simplified schematic of the logic train and module linkage used in applying the Incremental method.

"yes" or "no," depending on the land use activities of the watershed. If the answer is "yes," the user may proceed directly to the second module. If the answer is "no," the investigator is faced with the problem of determining the direction and magnitude of the change. Several avenues of analytical approach are available:

1. Monitoring watershed and associated habitat changes over a period of years to determine time trends.
2. Using simple watershed models and equations to estimate water, sediment, and chemical yields.
3. Investing in independent modeling expertise to build a sophisticated watershed model, or obtain the output of such models from other agencies.
4. Measuring the stream characteristics in a similarly affected watershed, and scaling those measurements up or down to fit the stream and watershed of interest.

Occasionally, an analyst may suspect watershed disequilibrium but is not able to authoritatively say so. If the analyst subsequently proceeds to the next module, it may have been falsely assumed even without saying so that the watershed is in equilibrium.

Warning signs indicating disequilibrium include: (1) more rapid runoff resulting in drastic high and low water levels of streams as compared with historical flow records; (2) large amounts of nutrients and sediments lost from the terrestrial to the aquatic component, often over short time periods; (3) increased fluctuations in stream temperature; (4) increased streambank erosion as the stream attempts to reestablish its equilibrium by channel cutting; and (5) decreased diversity and stability in the biotic component. . .as a result of the less stable environment.[31]

Water quality. Water quality is a dominant macrohabitat feature which, on a macro-scale, determines the longitudinal distribution of fishes and invertebrates in a river system. This is consistent with the river continuum theory of aquatic ecology. Theoretically, the distribution of water quality characteristics should be graded through a river system. That is, the headwaters should start out with the lowest temperature, lowest dissolved solids, and highest dissolved oxygen. As the river descends through the watershed, the temperature should systematically increase, as should the total dissolved organic and inorganic solids. If all systems operated this way, and all dissolved solids were nondecaying, a simple dilution model would suffice to relate flow regime to water quality.

Unfortunately, the real world is not so simple. Whereas longitudinal inversions are common in watersheds, they are the rule rather than the exception where water quality is concerned. Temperature and inorganic dissolved solids are among the few water quality parameters which often follow normal longitudinal gradations. However, even temperature is subject to longitudinal inversions wherever an abnormal heat source is present.

Concentrations of nonconservative pollutants seem to be functions of many system characteristics. Their initial concentrations are determined in the watershed, and are subject to augmentation (point sources) and dilution as they move downstream. However, as they move, they react with each other and with oxygen in the water. The reaction rates are functions of temperature, oxygen concentration, and initial concentration of the pollutant. These in turn are affected by travel time, mix rates, and dilution which are functions of channel geometry and flow regime. Therefore, when addressing water quality, it is virtually impossible to ignore watershed and hydraulic features of the stream.

As in the case of an assumed steady state for the watershed, it is frequently "convenient" to ignore water quality or to assume that maintenance of adequate water quality is guaranteed if sufficient flow is proved for fish habitat. For many streams, this assumption is valid. However, for many others, water quality is either a constraint on production, or will be under an altered flow regime. While some water allocation studies can legitimately ignore water quality, it should be the starting point for others. For some situations, consideration of water quality may enter the decision process at several points in the form of feedback loops (Figure 2).

The term "water quality" encompasses a wide variety of chemical and physical constituents of the water. In many cases, the potential limiting effects of water quality may be determined by a simple screening procedure. Such procedures basically give a "yes" or "no" answer to the question of the adequacy of water quality. Two important aspects are addressed to answer the questions: (1) determination of constituent concentrations, and (2) evaluation of the significance of those concentrations.

Records may be used to determine both spatial and flow-related changes in water quality. With no anticipated changes in source loading, such an empirical data base may be used directly to determine concentrations of various constituents at different streamflows. In many cases, such information is not available, and in others, changes in streamflows may be accompanied by changes in source loadings. In these cases, some type of water quality model will be required to evaluate constituent concentrations.

While the state-of-the-art in water quality concentration modeling has achieved a high degree of sophistication, the same cannot be said regarding the development of water quality biological evaluation criteria.[32] For the most part, biological criteria have been developed through the use of laboratory bioassays (See Mount and Gillett, this monograph). This type of controlled testing may have little relevance beyond defining threshold tolerances to animals in nature that are subjected to a variety of simultaneous stresses. Should water quality constituent concentrations fall within the criteria bounds this does not necessarily mean that no problem exists. Species growth and behavioral responses are the least documented in terms of present promulgated water quality standards.

Channel structure. Channel structure refers to features of the channel which provide resting and feeding areas for fish and fish-food organisms. These features include channel morphology and alignment, substrate size and distribution and cover characteristics.

The size and shape of a channel is a function of the geology of the area through which the stream flows, and of the flood flows carried by the stream. The alignment is often a function of the watershed characteristics, but is frequently altered by man's activity within the channel. Substrate size within the channel is dominated by the sediment yield from the watershed. The distribution of various substrate sizes in the stream is a function of both the yield and channel hydraulics.

Channel structure may affect the biological community directly through changes in sediment and cover characteristics. Indirect effects, primarily due to changes in channel size, shape, or alignment, are caused by redistribution of depths and velocities through the reach rendering the reach more or less usable by the organism of interest.

The contribution (yield) of water and sediment from the watershed to the stream system, in addition to providing the energy source (coarse particulate organic matter) and influencing the chemical quality, defines a dynamic equilibrium state with the stream channel structure. Disturbances upon the watershed often upset this equilibrium, resulting in a dramatic shift in channel form and sediment transport to compensate and move toward a new equilibrium state. Frequently, such a disturbance will cause changes in all three aspects of channel structure. However, it is possible to retain its present shape, yet experience changes in sediment size. Conversely, in many channel realignment (channelization) cases, the substrate size remains approximately constant, but the shape and alignment of the stream is radically altered.

Modification of the flow regime, with or without a watershed disturbance, may also upset the sediment-water equilibrium with similar results. A frequent mistake made during instream flow studies is to recommend a flow regime which is satisfactory from a microhabitat standpoint without checking to make sure the flow regime is sufficient to maintain the channel in its present form. Thus, maintaining a stability of microhabitat by guaranteeing a flow regime may impose an instability in the same microhabitat by modifying the channel shape and alignment.

The equilibrium status of a channel may often be determined by a screening process (as for water quality). Perhaps the easiest technique is to obtain United States Geological Survey stage-discharge rating curves for 5 to 10 years for gauging stations along the stream. An analysis of these rating curves can indicate equilibrium if the same rating curve has been used for several years to predict discharge from stage readings. Persistent changes due to aggradation or degradation of the bed are apparent in the frequency of change in the rating curves.

If the channel geometry and substrate are in equilibrium, they can be empirically described and interface with streamflow in hydraulic models. Likewise, if the channel shape is to be deliberately changed by channelization or by habitat improvement techniques, the channel shape, substrate, and cover characteristics may be designed and defined.

Where channel structure is not in equilibrium, the analyst is not helpless in assessing impacts of channel change. In those cases, several options exist:

1. The system may be monitored over a period of years to determine time trends.
2. Sediment routing on the macrohabitat level may also be determined empirically. This may be accomplished by sampling the suspended load and bedload entering and leaving a reach of stream. A sediment-discharge rating curve is thus constructed for each segment or reach boundary. From these empirically based curves one can determine the flows at which coarse sediment (it is necessary to segregate coarse load from wash load) is either scoured or deposited within the reach. However, the source of scour and areas of deposition can only be estimated. Simple mass balance equations can then be used to approximate bed elevation changes within the reach.
3. A state-of-the-art type sediment routing model may be applied to roughly determine the amount of scour or deposition within a segment of stream. Resultant streambed particle size may also be estimated. From this analysis (meta-morphology) a new channel geometry assuming the same alignment may be defined and passed on the Module 4 for microhabitat analysis.

Microhabitat simulation To reiterate, watershed and water quality characteristics are primarily longitudinal (macrohabitat) determinants of fish distribution and abundance. Channel structure and flow regime were discussed as they operate both on the macrohabitat level and microhabitat level. The geographic distribution of a species has been presented as a result of its interaction with its macrohabitat. However, within a segment of the macrohabitat where the longitudinal habitat characteristics are essentially homogeneous, fishes and invertebrates tend to select those microhabitat conditions most favorable to a particular species and size class.

Fishes have been shown to utilize instream habitat in a three-dimensional fashion which is determined by the interaction of channel structure, depth, and velocity.[24] For some fish species, "instream" or "overhead" cover further dictates distribution within a reach. The distribution of the flow parameters, depth, and velocity within a stream reach is very much a function of flow mechanics, sedimentology, and the channel form.

Therefore, the quantification of physical microhabitat must be addressed in a manner similar to the process used in water quality. First, changes in the physical environment must be identified and described. Second, the significance of those microhabitat changes in terms of their usability to the target species must be determined. It is this deterministic process which relates streamflow to the quantity and quality of microhabitat in the stream that is central to the state-of-the-art physical microhabitat analysis.

The greatest amount of research and development activity relevant to instream flow assessments during the 1970s was in this microhabitat description area and more specifically the physical microhabitat models used to evaluate usability under different streamflow regimes. Most models have been criticized because: (1) they were not supported by a rigorous mathematical development; (2) they lacked clear definition of the significance of the usability index; and (3) they were limited by the statistical techniques used to estimate weighting functions.

Mathematically, fish microhabitat models may be presented in the "USA" form:[33]

$$U = S \cdot A \quad (1)$$

where:

U = usability-which is a relative index value of the environment as habitat for the target organism,

S = suitability-which is the organism's voluntary or involuntary preference for combinations of environmental attribute values (i.e., depth, velocity, substrate), and

A = availability-which is the distribution of the values of the environmental attributes in a stream segment.

Recent work by the IFG has refined microhabitat analysis by developing improved hydraulic simulation models, weighted criteria for the life stages of target fish species, and the introduction of stochasitc or time-series streamflow data so that the habitat usability can be displayed over time for each species-life stage.

The first task undertaken by the IFG was the modification of both the conceptual view of the stream reach and the available hydraulic simulation models. Rather than viewing the stream reach as a series of depth, velocity, and substrate contours, the stream reach was modeled as a series of small cells or elements. The length of a cell is the distance halfway upstream and downstream from a transect to adjacent transects. Each transect is subdivided into a number of subsections, the width of each being translated as the width of the cell. This is illustrated in Figure 3.

State-of-the-art hydraulic models were then ungraded, so that instead of one average depth and velocity for a cross section, the depths and velocities of all the cells could be predicted. This was accomplished through improvements in the single

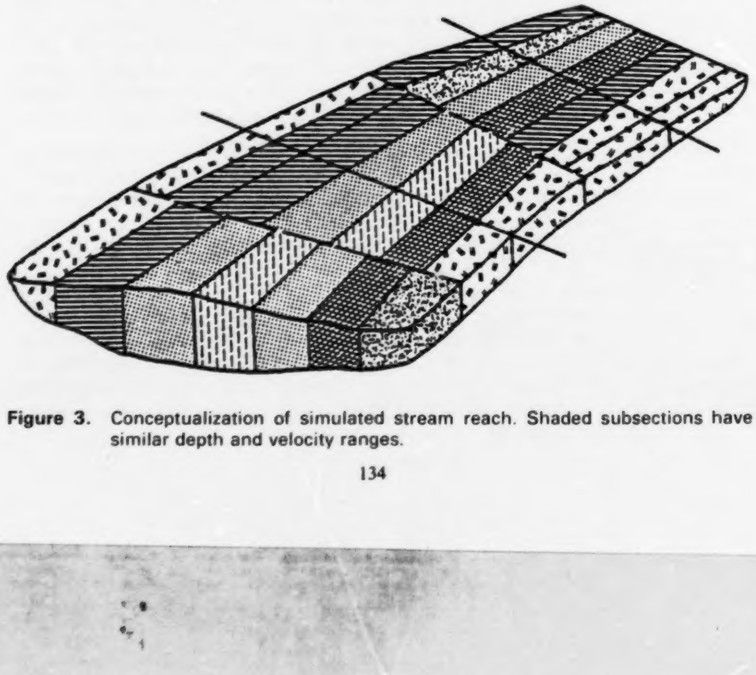


Figure 3. Conceptualization of simulated stream reach. Shaded subsections have similar depth and velocity ranges.

transect (IFG-1) and the multiple transect Water Surface Profile Program (IFG-2). A third multiple transect model (IFG-4) was developed for use in rapidly varied flow situations.[34]

The instream reach simulation takes the form of a multi-dimensional matrix (corresponding to the stream cells) of the calculated surface areas of a stream having different combinations of hydraulic parameters, i.e., depth, velocity, substrate, and cover when applicable. This matrix calculation provides a total summation of surface areas within the stream reach that have a given combination of hydraulic and structural attributes.

The significance of the hydraulic and channel structure features in each cell is then evaluated using procedures similar to those suggested by Waters.[18] Univariate curves showing the relative suitability of various stream attributes by life stage and species were compiled by IFG.[10] From these curves, a weighting factor for the depth, velocity, and substrate in each cell is determined. These weighting factors are multiplied together to estimate the composite suitability for that combination of variables, and this composite index is multiplied by the surface area of the cell. The product of the composite habitat suitability index and the cell surface are termed the "weighted usable area" of the cell. This process is repeated for each cell, with the weighted usable areas of all cells summed to determine the total weighted usable area of the stream reach.

By changing the flow, the distribution of depths and velocities changes in association with various substrate types and cover objects. As the flow changes the habitat value of each cell changes and is reflected in the total weighted usable area. These changes often balance out, i.e., some cells decline in usability while others increase. *Therefore, it is often possible to identify several discharges which provide the same measure of habitat usability.*

Mathematically, the basic concept is that in any instant of time and small area of the stream (dA), there exists a function $\psi(P)$ which related physical parameters (P) to the suitability of the area as physical habitat for a given species. The usability of the area is then:

$$d(WUA) = \psi(P)\, dA \qquad (2)$$

The term WUA is "weighted usable area" which is a physical habitat index. Integrating over a specified reach of stream, the weighted usable area for the reach is:

$$WUA = \int_A \psi(P)\, dA \qquad (3)$$

The physical parameters are simulated with predictive hydraulic models represented by:

$$P = H(I) \qquad (4)$$

The variables include depth, velocity, and substrate in the stream. The resulting equation is:

$$WUA = \int_A \psi(H(I))\, dA \qquad (5)$$

In the simplest form, the equation for the function for any cell or element *i* in the stream is:

$$\psi_i = P_v(V) \bullet P_d(D) \bullet P_s(S) \qquad (6)$$

where:

ψ is the habitat suitability function,
V is the velocity at a point,

D is the depth at the same point,
S is the substrate at that same point, and
P_v, P_d, and P_s are the functional relationships between the habitat suitability and velocity, depth, and substrate in the environment.

These functional relationships are species specific and are referred to a habitat suitability criteria.

For discrete elements, *i*, the average velocity, depth, and substrate values are used to solve Equation 6. The discrete elements are:

$$K_v(i) = P_v(v_i) \qquad (7)$$

$$K_d(i) = P_d(d_i) \qquad (8)$$

$$K_s(i) = P_s(s_i) \qquad (9)$$

where v_i, d_i, and s_i are the average values for the velocity, depth, and substrate in element *i*. The terms $K_v(i)$, $K_d(i)$, and $K_s(i)$ are the solutions for element *i*. Thus:

$$\psi = K_v(i) \bullet K_d(i) \bullet K_s(i) \qquad (10)$$

where ψ_i is the habitat suitability function for element *i*.

For discharge, the velocity and depth are simulated as a function of flow. The equation for ψ is solved for finite elements in the stream and the weighted usable area calculated using the equation:

$$WUA = \sum_{i=1}^{n} \psi_i A_i \qquad (11)$$

where ψ_i is the solution to Equation 6 for the element *i* and A_i is the area of element *i*.

The assumption basic to the model is that a species of fish will elect to live in physical conditions that are most suitable. Although there are many important physical factors, this model includes velocity, depth, substrate, and cover and, therefore, is applicable only to situations where these are the principal variables of concern.

A computerized physical habitat simulation system (PHABSIM) has been developed based upon the above logic.[35] While PHABSIM represents the synthesis and use of techniques which already existed, the examination of incremental changes in flow and habitat is new application of the technique as developed by IFG.

Water resource management utilizes water supply information based upon annual variation (annual hydrograph) and historical records (often displayed as monthly flows with certain recurrence intervals). The distribution of the hydraulic parameters of depth and velocity through a stream reach is a deterministic function of the flows (discharges) present, and can be described as a stochastic process utilizing existing hydraulic simulation techniques. The theory and application of these approaches to instream flow studies are discussed by Bovee and Milhous[34] and Stalnaker.[5]

Recent studies of fish habitat and channel maintenance flow requirements have shown that both are a function of the dynamic flow patterns of the stream hydrograph within a given year, and, most dramatically, among years. Thus, the flow requirements for maintaining any desired level of stream channel fish habitat structure must be dynamic and can only be protected by establishing *instream flow regimes* for wet years (sediment and bed load transport), average years (establishes the base level of fish production), and dry years (provides minimal survival conditions for "seed" stock necessary for replenishing the stream reach).[36]

Flow requirements may differ for various fish species and life stages as well as for other instream uses, thereby forcing the management agency, on behalf of the public, to define the management objectives for the stream reach in question.

Incremental Logic

The Incremental Methodology is a structured procedure providing a series of decision points and feedback loops that connect the major habitat components elaborated by Gorman and Karr.[29] The methodology itself is incremental because it is possible to start with some set of initial conditions, vary conditions slightly in any module, and determine the impact of the fluctuation. More specifically, the methodology is designed for iterative use of a large number of initial conditions.

For example, initial conditions might be:

1. Watershed unaltered and stable.
2. Water quality marginal but within bounds of criteria.
3. Channel structure in equilibrium with primarily a cobble bed containing extensive deposits of 10-25 mm gravel.

Given this set of initial conditions, one might proceed directly to calculations utilizing PHABSIM and determine habitat conditions for a median (1-in-2 year) flow regime. By evaluating the input discharges, it might be possible to determine a flow regime which requires less instream flow than the median flow regime, yet provides sufficient instream habitat.

For example, if by rerunning these habitat maintenance discharges through the water quality module, it is determined that this flow regime will result in dissolved oxygen concentrations during July and August which are too low when all additional flows were diverted from the stream. Two solutions could be explored:

1. Incrementally increase the flow until satisfactory levels of the dissolved oxygen concentrations are attained.
2. Incrementally increase the level of treatment to lower the biological oxygen demand concentration in the river. Various combinations of streamflow and levels of treatment should be investigated.

Further investigation may also show that the flow levels providing good fish habitat during February and June would allow deposition of sand-sized material over the gravel bars during the two peak sediment production months. Sedimentation resulting in the replacement of gravel with sand substrate in PHABSIM shows that while little effect on adult and juvenile fish habitat usability occurs, spawning and insect production will be radically curtailed. Therefore, it is determined that prevention of this sedimentation is desirable.

The flow during these two months is then increased until a flow level is found which is sufficient to prevent the deposition of sand on the gravel bars. However, on running these flows through PHABSIM, it may be found that the flows required for sediment transport are detrimental to newly hatched fry. This could be true since the effect of increased flows beyond the threshold level for transport of sand floods out shallow backwaters along the stream margin which provide the microhabitat required by the young fish. By continued iteration, it is possible to determine the flow regime which provides both fish habitat and sediment transport capability.

Not all scenarios will work out this nicely since it is not always possible to identify flows which will accommodate several uses at once. In such cases, some form of trade-off decision, or alternative management plan, must be formulated. From the previous example, suppose that flows required to move sediment were totally incompatible with the flows required by young fish. One mangement alternative might be to build sediment traps in tributaries to prevent the sand from reaching the stream. This technique might trigger undesirable side effects, such as degrading the bed, so it would have to be evaluated. Another alternative might be to wait until after the passage of the sediment transporting flow, and then stock fingerlings of the desired species. A third alternative might be to allow a high flow once every 3 or 4 years to remove accumulated sediment, with full knowledge that that year's recruits would be sacrificed. Regardless of the alternative selected, the Instream Flow Incremental Methodology provides a useful tool which can be employed to evaluate effects on the system.

Species Habitat Suitability Criteria

Previous investigators'[2,3,17,18] treatment of fish habitat criteria have assumed statistical independence among variables used in describing the preferred instream station (focal point) and spawning requirements comprising microhabitat conditions. Although this assumption has permeated instream flow literature for 10 years without challenge, the IFG has focused attention upon the mathematical theory responding to an expressed need for critical examination of this general assumption.[29]

Bovee and Cochnauer[37] and Bovee[10] assembled information relating the observations of fish types (including life stages as well as species) to the stream attributes of velocity, depth, and substrate. Water quality was observed (and in some cases inferred from other information) to be within suitable ranges so as not to affect the distribution of the fish. The field data included values of the attributes for each observed fish. However, no data were collected for attributes where fish were not observed, i.e., avoidance.

Univariate functions were obtained by fitting histograms of the data with piecewise linear curves. Due to the nature of the available data, the assumption of independence among variables was unavoidable. Joint suitability, $\psi(x)$, of a particular combination of variables was approximated by the product of the marginal distribution functions:

$$\psi(x) = f(v) \bullet f(d) \bullet f(s)$$

where:

f(v) = the marginal suitability function for velocity, integrated over all depths and substrates,
f(d) = the marginal suitability function for depth, integrated over all velocities and substrates, and
f(s) = the marginal suitability function for substrate, integrated over all velocities and depths.

The assumption of variable independence was tested by Voos,[33] Prewitt,[38] and Gore and Judy.[39] Prewitt concluded:

> ". . .in the more complex environments, WUA [weighted usable area] appeared to be quite stable across a broad range of discharges, ρ_p values [depth, velocity, substrate interactions], and preference curves supporting the hypothesis that with these complex stream physical habitats, the univariate approach effectively duplicated results of the multivariate approach."

Although the correlation coefficients from these studies were small, some statistically significant correlations were found. Therefore, future field studies should be conducted so as to describe these correlations (cross products) where practicable.

In addition to the lack of evidence indicating strong dependencies, there are advantages for estimating $\psi(\underline{x})$ from the product of the marginals. Because of the irregular shape of the function, none of the standard multivariate statistical distributions appear to model all of the shapes observed from the data. Defining the joint distribution in terms of the marginals allows the use of completely general, piecewise linear functions. Also, fishery scientists have a wealth of experience regarding the behavioral and physiological characteristics of fish in response to depth, velocity, substrate temperature, and other factors. This subjective information can be directly included in the joint function $\psi(\underline{x})$ by controlling the form of the marginals. Consequently, habitat evaluations can incorporate the best judgment of fishery scientists.

LOOKING FORWARD TO THE 1980s

Although major advances were made during the 1970s, emphasis in three areas is needed in the next few years to capitalize on the foundation established during the decade of the 1970s. First, continued development of physical-chemical simulation techniques should be coupled with accelerated research efforts to establish criteria for interpreting the results of these simulations for a wider variety of target species. Conceptual models must be developed before additional elements can be factored into the instream assessments of water planning. These elements should include freshwater inflow to estuaries, sediment transport and channel change, water requirements of riparian vegetation and wetlands, and the response of aquatic organisms to rapid fluctuations resulting from hydropeaking and pumpback storage.

Lastly, focused attention is needed in the legal-institutional arena. Although several states have established a vehicle for providing legal protection under state law, in other states there has been virtually no progress. The Clean Water Act, as amended (PL91-500 and PL95-217) requires that the waters of the Nation be fishable and swimmable by 1983. The U.S. Environmental Protection Agency has promulgated standards through the assistance of the state water quality agencies. For the most part, these standards are based on what it takes to kill fish or conversely keep them alive (lethal doses). To meet the intent of the law, we need to do more. We need to provide sufficient habitat. Numerous studies including the Second National Water Assessment have called for an integration of water quality and water quantity segments of the water planning community. A major advance toward this integration would be to make depth and velocity water quality parameters for which state quantity standards could be set. In early 1980, Region 8 of the U.S. Environmental Protection Agency produced a draft white paper describing several major environmental threats which require attention. Among these was the promulgation of water *quantity* standards.

Several 208 planning agencies, operating under existing legislation, are now attempting to implement water quantity standards through their 208 water quality plan. The Clean Water Act provides that states may use federal funds available through Section 106 to research and develop such standards. The Act requires that every three years the states update and upgrade the water quality standards. Coupling quantity to quality standards provides an orderly process through which the eventual goal of fishable and swimmable water could be realized.

By accelerated attention to the life history requirements of the fishes of concern, e.g., management objectives or target species, coupled with the promulgation of guidelines for establishing water quantity standards, the decade of the 1980s could see continued momentum in efforts to protect instream values across the Nation.

REFERENCES

1. U.S. Water Resources Council. 1968. The first national water assessment. Washington, D.C.
2. Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for the determination of stream resource flow requirements: an assessment. FWS/OBS-76/03. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 199 pp.
3. Orsborn, J. F., and C. H. Allman, eds. 1976. Instream flow needs. Proc. Spec. Conf. Boise, Idaho. (2 Volumes) American Fisheries Society. Bethesda, Md. 1157 pp.
4. Wesche, T. A., and P. A. Rechard. 1980. Instream flow research needs and fisheries methodology. Eisenhower Consortium Bull. No. 8. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

5. Stalnaker, C. B. 1981. Effects on fisheries of abstractions and perturbations in streamflow. Proc. International Symposium on Fishery Resources Allocations. April 1980. F.A.O. Vichy, France.
6. Bayha, K. 1978. Instream flow methodologies for regional and national assessments: Instream Flow Information Paper No. 7. FWS/OBS-78/61. Office of Biological Services. Fish and Wildlife Service, USDI. Cooperative Instream Flow Service Group. Fort Collins, Colo.
7. Fraser, J. C. 1979. Emergency response (How should administrators respond to a request for an opinion on abstraction within one month?). pp. 60-66 *In* The effects of water abstraction on fisheries. Scott, D., ed. National Water Protection Committee of Acclimatisation Society. Dunedin, New Zealand.
8. Stalnaker, C. B. 1980. Low flow as a limiting factor in warmwater streams. Proc. Warmwater Streams Symposium. Knoxville, Tenn. Southern Division, American Fisheries Society. Bethesda, Md.
9. Tessman, S. A. 1980. Environmental assessment: reconnaissance elements of the Western Dakotas Region of South Dakota. Study Report. South Dakota State University, Brookings, S.D.
10. Bovee, K. D. 1978. Probability-of-use criteria for the family salmonidae. Instream Flow Information Paper No. 4. FWS/OBS-78/07. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 80 pp.
11. Giger, R. D. 1973. Streamflow requirements for salmonids. Anadromous Fish Project 14-16-0001-4150. Region Wildlife Comm. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 117 pp.
12. Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Pacific Gas and Electric Co. Emeryville, Calif. 97 pp.
13. Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Canada.
14. Shirvell, C. S. 1979. The effects of abstraction on a trout stream. Ph.D. Thesis. University of Otago. Dunedin, New Zealand.
15. Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. Amer. Zool. 19:331-343.
16. Shuter, B. J., J. A. MacLean, F. E. J. Fry, and H. A. Regier. 1980. Stochastic simulation of temperature effects on first-year survival of smallmouth bass. Trans. Amer. Fish. Soc. 109:1-34.
17. Collins, M. R., R. W. Smith, and G. T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species. Water-Supply Paper No. 1968. Geological Survey, USDI. Washington, D.C. 109 pp.
18. Water, B. F. 1976. A methodology for evaluating the effects of different streamflows on salmonid habitat. pp. 154-267. *In* Instream flow needs. Orsborn, J., and C. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.
19. Cochnauer, T. 1976. Instream flow techniques for large rivers. pp. 387-400. *In* Instream flow needs. Orsborn, J. F., and C. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.
20. Dooley, J. M. 1976. Application of the U.S. Bureau of Reclamation Water Surface Profile Program (WSP). pp. 478-496. *In* Instream flow needs. Orsborn, J., and C. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.
21. Elser, A. A. 1976. Use and reliability of water surface profile program data on a Montana prairie stream. pp. 496-505. *In* Instream flow needs. Orsborn, J. F., and D. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.

22. White, R. G. 1976. A methodology for recommending stream resource maintenance flows for large rivers. pp. 376-386. *In* Instream flow needs. Orsborn, J. F., and C. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.
23. Workman, D. L. 1976. Use of the water surface profile program in determining instream flow needs in Sixteen-mile Creek, Montana. pp. 505-513. *In* Instream flow needs. Orsborn, J. F., and C. H. Allman, eds. Vol. 2. Proc. Spec. Conf. Boise, Idaho. American Fisheries Society. Bethesda, Md.
24. Cooperative Instream Flow Service Group. (in preparation) Instream flow techniques in water resource planning and management. Office of Biological Services, Instream Flow Service Group. Fish and Wildlife Service, USDI. Fort Collins, Colo.
25. Cummins, K., and R. Mattingly. 1981. This monograph.
26. Everest, F. H., and D. H. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Can. 29:91-100.
27. Jenkins, T. M. 1969. Social structure, position choice and micro-distribution of two trout species (*Salmon trutta* and *Salmo gairdneri*) resident in mountain streams. Animal Behav. Monogr. 2:57-123.
28. Wickham, G. M. 1967. Physical microhabitats of trout. M.S. Thesis. Colorado State University. Fort Collins, Colo. 42 pp.
29. Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology. 59(3):507-515.
30. Cooperative Instream Flow Service Group. (in preparation). A user's guide to the instream flow incremental methodology. Instream Flow Information Paper No. 12. Office of Biological Services. Fish and Wildlife Service, USDI. Fort Collins, Colo.
31. Karr, J. R., and I. J. Schlosser. 1978. Water resources and the land water interface. Science. 201:229-234.
32. Neuhold, J. M., D. B. Porcella, and G. S. Innis. 1979. Selection of variables for evaluation of stream ecosystems in relationship to watershed activities. pp. 125-144. *In* Proceedings workshop on index construction for use in high mountain watershed management. UWRL/G-79/01. Utah Water Research Lab. Utah State University. Logan, Utah.
33. Voos, K. A. 1980. Simulated use of the exponential polynomial/maximum likelihood technique in developing suitability functions for fish habitat. Ph.D. Dissertation. Utah State University. Logan, Utah. 86 pp.
34. Bovee, K. D., and R. T. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. Instream Flow Information Paper No. 5. FWS/OBS-78/33. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 130 pp.
35. Milhous, R. T., D. L. Wagner, and T. Waddle. 1981. User's guide to the physical habitat simulation system (PHABSIM). Instream Flow Information Paper No. 11. FWS/OBS-81/43. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 242 pp.
36. Stalnaker, C. B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. pp. 321-337. *In* The ecology of regulated streams. Ward, J. V., and J. A. Stanford, eds. Plenum Press. New York, N.Y.
37. Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. Instream Flow Information Paper No. 3. FWS/OBS-77/63. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 38 pp.

38. Prewitt, C. G. 1982. Effects of depth-velocity correlations on aquatic physical habitat usability estimates. Ph.D. Dissertation. Colorado State Univ. Fort Collins, Colo. 92 pp.

39. Gore, J. A., and R. D. Judy, Jr. 1981. Predictive models of benthic macroinvertebrates density for use in instream flow studies and regulated flow management. Can. J. Fish. and Aquatic Sci. 39(11):1363-1370. (J. Fish. Res. Bd. Can.).

RESEARCH PROGRESS ON ECOTOXICOLOGY

PART 1

SINGLE SPECIES TESTS

Donald I. Mount

While research on and testing of single species have involved (in varying degrees) wild mammals, reptiles, and amphibians, most effort has been directed towards aquatic life and birds. Far more environmental toxicology resources have been expended on aquatic life, perhaps because early environmental control efforts almost exclusively focused on water pollution abatement. Only more recently have air and terrestrial pollution abatement become increasingly important. Undoubtedly, the extreme sensitivity of aquatic organisms to many of the early insecticides and their rather high exposure to direct spraying and runoff made them among the first to show obvious harm.

The following highlights from the 1970s decade of progress in single species testing are concentrated mainly on aquatic life and to a lesser extent on birds. Many of the future milestones achieved will probably occur in wild mammal and other terrestrial groups if present trends in atmospheric pollution (such as acid rain) continue.

STATE OF THE ART IN 1970

Acute Tests

Until 1970 most of the small number of laboratories doing research on environmental toxicology had been concentrating on acute tests consisting of single doses for birds and mammals or short-term static exposures for aquatic animals. Analytical techniques were primitive compared to today's methods. Few attempted to confirm exposure with chemical measurements. Budgets were small and only public agencies and universities were active. Only a handful of industries had environmental toxicologists, and their combined effort was small.

During the early part of the 1960s (and even before), most attention was focused on the effects of low dissolved oxygen (D.O.), metals, cyanide and domestic sewage on aquatic life. With the expanded use of chlorinated hydrocarbon insecticides and organophosphates, research on aquatic life effects shifted mostly to these contaminants. The impacts of these insecticides, mostly the chlorinated organic ones, stimulated much of the early work on bird toxicology, an emphasis that exists even today.

Test Methods

Much of the effort had to be focused on the development of toxicity test methods. There was little available experience to draw upon for keeping thriving populations of birds in laboratory conditions. Most interest and concern centered on the effects of

---

The Author: Dr. Mount is currently senior Research Aquatic Biologist, U.S. Environmental Protection Agency, Duluth, Minnesota. He has published extensively on bioassay procedures and is a foremost authority on the subject.

contaminants on birds of prey and waterfowl. Poultry husbandry was of little help for these groups. For aquatic life, fish culture which provided large numbers of a variety of fishes for stocking gave a head start to experimentalists. However, this was clearly not the case for saltwater species.

Development of economical and reliable dosing equipment required substantial effort, especially for aquatic life where maintenance of water concentrations was a problem. Many pesticides in particular were not very water soluble, and difficulty was encountered in maintaining desired exposure concentrations. Late in the decade, Mount and Brungs[1] developed a simple, inexpensive device that enabled researchers to achieve adequate dosing. Figure 1 shows a modern apparatus for testing toxicity of substances to aquatic life.

Little is known about handling invertebrates in the laboratory and development of methods for maintaining them lagged behind those for fish. Gradually, however,

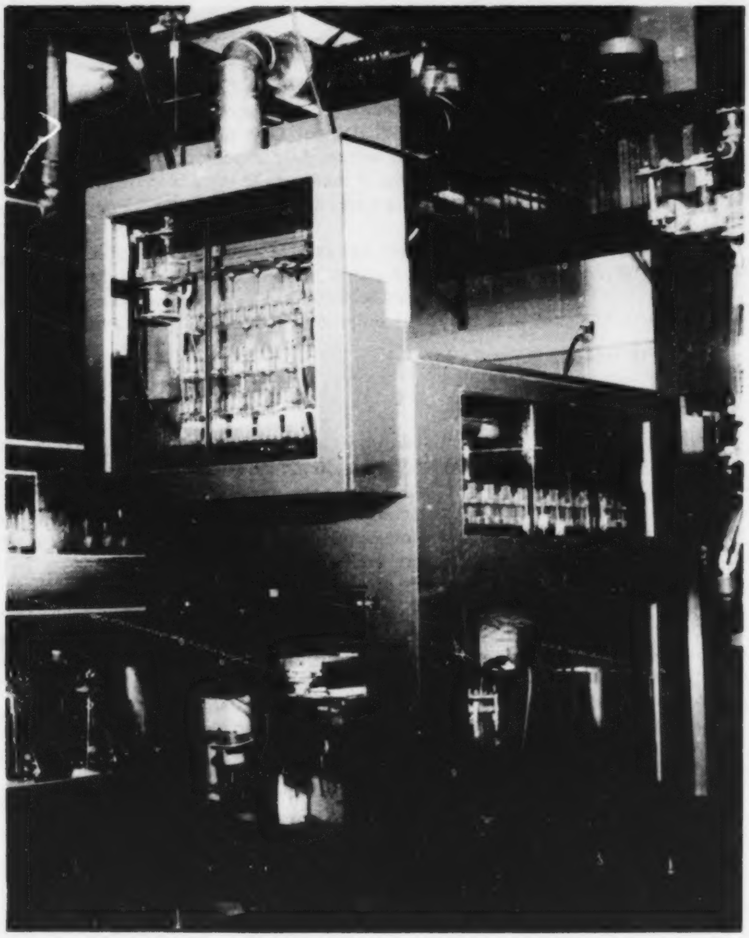


Figure 1. A modern aquatic toxicity testing system for hazardous materials.

techniques were also found for keeping waterfowl and birds of prey. Also, surrogates for highly desired game birds were located—ones that did well in research labs.

Few facilities had suitable pens for birds or a water supply for aquatic testing. Flow-through techniques were sought, but lack of equipment and water supply hindered progress. Near the end of the decade, Olson and Foster[2] published a paper on the effects of chromium on rainbow trout. Their research involved flow-through techniques. This was one of the first published works using a long exposure period. In 1967, Mount and Stephan[3] published on the first life cycle toxicity test. Equipment shortcomings and the difficulty of obtaining successful spawning had previously hindered such testing.

Water Quality Standards

The 1965 Federal Water Pollution Control Act[4] required water quality standards for interstate waters. The information necessary to establish these standards was sparse but the need was a strong incentive for generating quantitative toxicity data. This incentive "boosted into orbit" aquatic toxicology. The Federal Insecticide, Fungicide and Rodenticide Act was also strengthened and more bird data were required for pesticide registration. Late in the decade the Report of the Committee on Water Quality Criteria[5] was published as a summary of environmental toxicology data to date.

As the 1970s dawned, Earth Day and the emotion that preceded and followed it brought unprecedented attention, expertise and budget to environmental toxicology. What, up to that time, had been unimportant and dull research suddenly became the "in" thing to do.

PROGRESS DURING THE SEVENTIES

Introduction

Space in this report permits touching on only a few of the many achievements made from 1970 to 1980. While not an achievement of research *per se*, the numerous legal actions growing out of stricter environmental control and improvement efforts forced many environmental toxicologists and biologists to testify under oath. Specifics are hard to cite, but these experiences led to a maturity in data interpretation and a sharpening of the relevancy of research in the entire field. A new dimension was added to research: it had to be admissible as legal evidence.

The same legal activity and increasing regulatory controls caused the private sector to hire many toxicologists. In addition, numerous contract laboratories emerged which provided the facilities and staff to develop data to rebut the regulatory agency scientists. Thus, the decade has seen an immense growth in the number of competent environmental toxicologists in the private sector. Meetings of people in the discipline during the 1960s were dominated by governmental and academic types. During the 1970s, such meetings attracted larger numbers from the growing ranks in the private sector. By 1980, governmental and academic (excepting those academic scientists who are paid consultants) scientists are not uncommonly in the minority.

Progress on Methods

The use of chronic life cycle tests on aquatic organisms and birds expanded rapidly even though the cost of each test amounted to tens of thousands of dollars. Journals devoted to advancing research findings were willing to publish such work because it was new. That changed, however, by 1980. Only a few species have been used in such tests and the work became routine and less acceptable for journals.

Because of the bioconcentration (and bioaccumulation) potential of certain pesticides (and subsequent United States Food and Drug Administration actions on high residues in commercial fishes and some wildlife species), laboratory methods to measure this property of chemicals advanced rapidly. During the last few years, measurement of residues has approached standardization, and prediction of residues from chemical structure appears to be within reach.

The role of DDE in causing egg shell thinning in birds was more clearly elucidated, leading to an almost certain explanation for the decline in populations of certain groups of birds. The banning of many uses of some "hard" insecticides and the subsequent recovery of wild populations confirmed the laboratory findings. The dramatic drop in DDT residues in Lake Michigan fishes provided another validation that laboratory-derived data were indeed applicable to the field situation. Laboratory data are much cheaper and quicker to obtain than are field data. Furthermore, they can be obtained before the problem exists in the natural environment. Such data then have the virtue of being predictive rather than retrospective in nature as field data, by necessity, must be. This virtue is an important one as the pre-market testing requirements of the Toxic Substances Control Act are promulgated.

The demonstration by Ringer[6] that mink on mink farms suffered reduced reproductive capacity as a result of xenobiotic chemical residues in their food provided more evidence that everything is connected to everything. More importantly, several of the findings mentioned above pointed up the serious consequences of persistent residue-forming chemicals widely released into the environment. Just as biochemical oxygen demand (BOD) in the 1950s and insecticides in the 1960s received the research spotlight, perhaps one could conclude that residues of man-made chemicals in fish and wildlife constituted one main focus of attention in the 1970s. Indeed, perhaps more regulatory actions and more headlines have stemmed from excessive residues than from direct toxicity from the ambient medium: air or water.

The close of the decade, with the passage of the Toxic Substances Control Act and the realization that the number of compounds in use was in the tens of thousands, created a demand for rapid and inexpensive tests to make safety judgments on more chemicals for a given amount of resources. Thus, life cycle tests lasting many months or one or more years are waning and shorter toxicity tests are being developed to replace them. Toxicologists perhaps saw that knowing something about nearly all chemicals was more valuable for protecting the environment than knowing a lot about only a few chemicals. The recent leveling or even decline in research budgets and staff made this change an obvious necessity in order to stretch shrinking resources. The exceedingly short time frames for decisionmaking under the Toxic Substances Control Act vividly brought to our attention the need for faster tests.

Hazard Assessment

As environmental control progressed, environmental toxicologists recognized several other principles as important to their success. For one, toxicity of a chemical was not the whole story. The expected environmental concentrations at the critical place and times were equally as important as toxicity in deciding what the actual impact would be. As the decade has progressed, environmental chemistry and toxicology have been drawn ever closer together. Both are necessary to make valid decisions. Knowledge of such phenomena as environmental compartmentalization (deposition in sediment or residue formation in animals), persistence, volatility and degradation products is needed along with toxicity data to make judgments of effects in the ecosystem. Indeed, environmental chemistry has grown to play a vital role in laboratory toxicology.

Toxicologists, recognizing the need to test more than one species and also the resource constraints, began to question what and how many species should be tested. This concern led to new terms describing new concepts such as tiered testing, triggers, surrogate species and functional indicators. More and more, practical decision-making needs were forcing toxicologists to select point concentrations above which harm would occur and below which safety was assured (often without the hedge of a safety factor). Such a job is at least exceedingly difficult when, in fact, one is faced with a continuum of response in which no such threshold is apparent. The need for "a number" caused the U.S. Environmental Protection Agency (EPA) to abandon the expert judgment approach used in the book entitled *Water Quality Criteria*—1972,[7] and to adopt (for the EPA—Natural Resources Defense Council Consent Decree) a much more rigid but reproducible method of picking a point value for use as a threshold concentration.

The decade closed before the wisdom or acceptance of that approach had become clear. While only known by a very few scientists at the time of this writing, the development of such methodology demanded an unprecedented and objective examination of the existing aquatic toxicity data base. That examination shattered many perceptions held so long that they had become accepted as axioms. Only at the time of this writing are these perceptions being set forth for the profession to examine. We feel certain that as they are studied and their meaning understood, they will bring about a reversal in the priority of information needs as we saw them during the 1970s. For example, the difference in sensitivity among aquatic species has been known to be large. That that difference is frequently 100 to 1,000 times greater than the difference between acute and chronic effect levels for many chemicals has not been generally recognized. The suggestion is that relatively more resources should be expended on studying acute toxicity on more species rather than on chronic toxicity for a few species for a given amount of testing. This will not be readily accepted by many toxicologists.

Applications

The progress on methods and data generation made during the 1970s decade was applied as it became available in environmental regulation, principally for water pollution regulation.

Under the pesticide registration requirements, impact testing of aquatic species was initiated. No longer were human health effects the only major concern in approval. Many water quality standards were adopted by the states. These standards were intended to define an acceptable maximum level of contamination of water that would not jeopardize water uses, including propagation of aquatic life. Such standards were based almost exclusively on single species toxicity tests.

More recently, the Toxic Substances Control Act (among other things) requires manufacturers to obtain approval to produce new chemicals. Test standards describing useful tests to perform for obtaining necessary data are currently being finalized for the Federal Register. These standards, by and large, are single species tests developed during the seventies. Decisions based on single species tests will have a profound effect on the economy as well as the environment.

An increased interest has also been expressed recently in limiting the toxicity of effluents as well as requiring some minimum level of treatment technology. Again, single species tests are being viewed as the best and most practical way to measure and limit toxicity emissions.

While the limitations of single species tests are many, they do have marked advantages of cost and brevity as compared to our currently available, more complex tests such as microcosms. During a decade when gross pollution was being cleaned up and public support was strong, single species tests served us well. The trend now is towards fine tuning our regulatory efforts and eliminating more subtle effects. Many are seriously asking whether we have overregulated. The 1980s may be a time when the precise use and limitation of single species tests is more clearly delineated and we become more aware of exactly how they should be used.

FUTURE RESEARCH

The 1980s begin with a lessening of the fervor that was so much a part of Earth Day and the years following. The public's sentiment will have much to do with the course of scientific investigation because much of the research not required by regulations is financed by public funds. Perhaps public opinion will be shaped most importantly by the unfolding of the energy picture. In trying to look ahead at environmental toxicology needs, let us assume some reasonably suitable adjustment to our energy situation is achieved.

We can then expect even more pressure for shorter, cheaper and simpler tests to deal with the thousands of new chemicals that will come into use. The use of such tests will pass from research into the realm of routine data generation. Data production, an important activity in environmental toxicology research during the 1970s, will decrease. Much more effort will be expended on predicting rather than actually measuring toxicity. The use of predictions based on chemical structure and properties will receive much more attention.

The practical usefulness of microcosms will be resolved. A much better perception of their value and shortcomings will take their proper place—whatever that turns out to be. We will give much more attention to careful selection of the best species to test for given needs.

Because a large data base has been developed during the past decade, we are likely to increase our perusal of that data and begin to draw generalizations and principles from them. These will enable us to build on the foundation of the seventies at a much accelerated rate and will help immensely in making more accurate predictions. We should be able to forecast toxic responses from chemical groups, much as is now possible in pharmacology.

Perhaps the most profound change in direction will occur if global contamination problems continue to grow (for example, acid precipitation). Environmental regulation has largely been concerned with small areas and particular species. The more ecologically inclined have pushed hard for greater consideration of functional endpoints such as photosynthetic rates. Such functional measures of impact have not played a key role in regulation up to 1980. Global or continental contamination has the potential to affect our very life support system, for example, the oxygen/carbon dioxide balance in the atmosphere. Both the environmental toxicologist and the public will then better appreciate the need for protection of functions and may be much less concerned about sport fish and vanishing species. As a concomitant need, we will more carefully examine the community significance of endpoints of effect now used in single species toxicity tests. The meaning to communities of a 10% growth reduction in a toxicity test will need to be ascertained.

In summary we can look back and look forward and characterize the decades as follows:

The fifties were concerned with domestic sewage.

The sixties consisted of a period of initial methods development and testing of pesticides.

The seventies were a period of rapid improvements in methods and data generation.

The eighties are likely to be a period of rapid progress in prediction and more efficient use of resources because of the foundation developed in the previous decade.

It seems worth repeating that the direction our efforts take will be very much dictated by how major issues such as those connected with energy are resolved or not resolved by society.

REFERENCES

1. Mount, D. I., and W. A. Brungs. 1967. A simplified dosing apparatus for fish toxicology studies. Water Res. 1: 21-29.

2. Olson, P. A., and R. F. Foster. 1956. Effect of chronic exposure to sodium dichromate on young chinook salmon and rainbow trout. HW-41500 (Unclassified).
3. Mount, D. I., and C. E. Stephan. 1967. A method for establishing acceptable toxicant limits for fish—malathion and the butoxyethanol ester of 2,4-D. Trans. Amer. Fish. Soc. 96(2):185-193.
4. Federal Water Pollution Control Act Amendments of 1972 to the Water Quality Act of 1965. Federal Register. Washington, D.C.
5. Federal Water Pollution Control Administration. 1968. Water quality criteria—report of the National Technical Advisory Committee to the Secretary of the Interior. U.S. Dept. Interior, Washington, D.C., April 1, 1968. 234 pp.
6. Ringer, R. K., R. J. Aulerich, and M. Zabik. 1972. Effect of dietary polychlorinated biphenyls on growth and reproduction of the mink. *In*: 164th National Meeting of the American Chemical Society. 12(2): 149-154.
7. Environmental Studies Board. 1973. Water Quality Criteria 1972—A report of the Committee on Water Quality Criteria. EPA-R3-73-003. U.S. Environmental Protection Agency. Washington, D.C. 594 pp.

RESEARCH PROGRESS ON ECOTOXICOLOGY
PART 2
LABORATORY MICROCOSM TESTS

James W. Gillett

INTRODUCTION

Understanding the role that pollution plays in irretrievable losses of resources is critical to the ecological and economic survival of man. It has long been acknowledged that fisheries, forests, agricultural lands, game, and other wild species of plants and animals are at risk from increased environmental pollution. Yet, only as man came to rely more heavily on chemicals derived in laboratories was the empirical knowledge from studies in the field, lake, and stream also addressed in the laboratory. Attempts to quantify biological measurements of impact were undertaken in earnest during the decades of the 1950s and 1960s. These measurements became critical in the evolution of an assessment logic and control approach that has seen increasing reliance on laboratory testing.

Laboratory testing is now the backbone of such evaluations as pesticide and drug registration processes, pre-manufacturing review of toxic substances, worker and consumer safety studies, and practically every other aspect of chemical regulation. It encompasses not only biological effects, but, just as importantly, the fate and movement of the chemical pollutants. Because of sensitivity, specificity, and cost, biological testing has again come to be used in evaluation of complex effluents (such as waste streams from coal gasification plants). Increased attention to precise physiochemical measurements, structure-activity relationships, and comparative toxicologic relationships now has become part of an approach to protecting the environment that is easily taken for granted. We only have to recall how much of a struggle it has been to reach our current state of "knowledgeable ignorance."

A decade ago biologists were literally swamped with needs created by the growing awareness of the impact of pollutants. Increasingly sophisticated chemical analysis revealed the presence of ubiquitous and persistent toxicants such as 1,1-(p-chlorophenyl)-2,2,2-trichloroethane (DDT) and polychlorinated biphenyls (PCB). Arguments over which pollutant was most significantly involved in major ecological problems—loss of certain fisheries, failure of bird reproduction, increasing eutrophication of lakes, etc.—led to acrimonious finger-pointing as to which polluter was going to have to bear the burden of cleaning up. The potent awakening of environmental concerns in the mid-1960s engendered more questions and rhetoric than solutions.

By 1970, certain scientific tools were beginning to be recognized and accepted. These tools consisted of various laboratory tests which depended upon standardized conditions for production of data which, if they did not represent exactly what went

---

The Author: Dr. Gillett is Leader of the U.S. Environmental Protection Agency's Chemical Biodegradation/Soil Microbiology Team at the Environmental Research Laboratory at Corvallis, Oregon. Prior to joining the U.S. EPA in 1974, Dr. Gillett was Associate Professor of Agricultural Chemistry at Oregon State University. His research interests include pesticide toxicology and physical and mathematical modeling of the environment.

on in the field, at least were consistent enough to be applied to environmental decisions. This acceptance was based on recognition of certain principles taken from many diverse fields. Moreover, this acceptance was based on very pragmatic concerns:

- We had neither the time nor the skills to examine all chemicals in all environments against all species at risk.
- We recognized the critical role that environmental conditions played in determining the outcome of exposure to a toxicant, but were helpless in controlling these conditions in the field, lake or stream.
- The field of environmental chemodynamics—the study of the fate and movement of chemicals in environmental systems—was being established as interrelating physicochemical characteristics and environmental processes.
- For decades, successful use of white rats and mice in the health sciences and of a variety of invertebrates and cold-blooded vertebrates in pesticide studies had shown the ways in which laboratory knowledge could be used.
- People were becoming increasingly resistant to "on the job" testing of chemicals, recalling the challenge of the mid-1930s of "100 Million Guinea Pigs."[1] Moreover, new environmental laws meant that any such use would have to be limited to chemicals which had no predictable adverse impact.
- The concepts of ecology and what was to be called ecotoxicology began to be expressed in terms of quantitative processes and models for which precise measurements were needed.

Measurement of the fate and effects of a toxic pollutant under controlled laboratory conditions therefore became the first step in the predictive evaluation of adverse impact. These measurements can be contrasted with field assessments or monitoring. The former approach is applicable even before a chemical is used or manufactured in great quantities. In the latter instance, we may be searching for the causes to a problem, seeking confirmation of laboratory tests, or simply assessing the presence of chemicals or biologically active materials in air, water, soil or biota.

Over the past decade, there have been enacted a number of federal and state laws which literally demand that the protection of wildlife resources and habitat be considered, either specifically or in terms of human welfare. The most specific laws have been the most recent: the Toxic Substances Control Act (TSCA), amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Resources Conservation and Recovery Act (RCRA). Furthermore, court decisions and consent decrees have established critical problems and/or chemicals for which testing must be rapid, accurate, inexpensive and cost-effective.

In spite of great strides in toxicology, ecology, and environmental chemistry, evaluating the consequences of chemical usage on pollutant releases remains complex and hazardous as building a network of roads and bridges through a barely explored swamp. On one side are the very real and known dangers to man and supporting ecosystems of chemicals inadvertently released or carelessly distributed. Consequences of ineffective action with regard to these dangers could range from genetic damage and loss of entire populations to damaged agricultural and silvicultural capacity or loss of fisheries resources. On the other side of the equally real economic and social implications of chemical production and use and other anthropogenic sources of pollution. The consequences of unnecessary regulation or overreaction could affect the quality of life and, indeed, even the survival of millions of people and other species.

The various Acts are authorizations to build these bridges through poorly chartered territory, but the map is being crafted, in no small part, by scientists in the several areas of ecotoxicology and environmental chemistry. The latter is a parallel path to biological effects; without that knowledge there is no direct way to place knowledge of ecotoxicological effects in perspective. Similarly, more presence of a chemical does not necessarily indicate a threat; its concentration must be considered in relation to its biological activities. These two "lanes" constitute the exposure and hazard portions of the assessment roadway. Together they yield risk assessment, which is based on the primary dictum of toxicologists extending to Paracelsus: "Dose always determines toxicity."

Some hard realities intrude in efforts to build such a system for evaluating chemicals specifically and pollution in general. We had decades to build the Panama Canal and a decade of national effort to put a man on the moon. The law says that we should already be enforcing all aspects of the several acts, but there are not enough scientists and laboratories in existence to test the 60,000 known toxic substances and thousands of product waste streams for all known adverse effects. Some roads can be constructed for limited purposes—pesticides, drugs, etc.—but it is not possible to build sufficient bridges for all the traffic.

There are many steps in the sequence of events from the time a scientist detects some adverse response in the laboratory or the field to the time at which a regulatory agency or private body can take effective action. Bridges must be built from one solid foundation to another, linking a specific test response to projections of risk through exposure and the explicit implications of the consequences of that risk.

During the past decade, the basic component for building these bridges has been developed in the laboratory: the single species toxicity test. In the laboratories of the Fish and Wildlife Service and the former U.S. Public Health Service groups (later to become the U.S. Environmental Protection Agency), in private industry and non-profit institutions, and in colleges and universities, means have been found to test the acute (short term or single-exposure) and chronic toxicity of practically the entire taxa of plants and animals.

The use of the single species assay is the dominant feature of modern ecotoxicology. By carefully selecting test species and controlling the environmental conditions of exposure, a powerful tool has been created that by extension can serve from the early stages of evaluation (identification of bioactivity) on through to more complex aspects (economic and ecologic evaluation).

As the single-species assay was becoming the primary tool of ecotoxicology, advances in ecology and environmental chemistry served to focus attention on the systems-level aspects of the fate and effects of chemicals. This approach was promoted by two familiar causes. It became theoretically imperative to examine the set of interacting processes and components (biological and chemical) that produced ecosystem response, and it became increasingly feasible to do so. The success of the single-species assay, advances in chemical separation and quantification, improvements in controlled environments, and increasing ease of high speed computation of statistical mathematical models contributed to the practicality of systems-level attack on pollution problems. Recognition of the need for attaining better understanding in the laboratory provided the impetus.

This paper examines the strengths and weaknesses of these building blocks of understanding and how they fit into the logical framework that may get us across the swamp.

LABORATORY MICROCOSM TESTS

A systems-level laboratory attack on the problems of pollution can begin with an excised portion of the "real world" brought into the laboratory, with an artificial assemblage, or with a mathematical model of processes. Such a model is usually a product of laboratory measurements of biological and physiochemical processes and characteristics or species functions. Hence, our attention should be directed first to the place where artificial and natural assemblages are maintained and studied in the laboratory.

Ecosystems have certain critical biological functions[2] and characteristic structures that may be threatened by stress and pollutants. These threats include:

- Primary Productivity—loss of energy-trapping ability to an ecosystem.
- Growth—loss or severe alteration of material-sequestering ability among the trophic levels and their constituents.
- Reproduction and Development—extreme fluctuations of populations and age-class distributions.
- Decomposition—interruption in nutrient cycling, mineralization, and mobilization.
- Key Species—loss of species critical to or characteristic of ecosystem function (in contrast to economic or aesthetic values).
- Structural Diversity—extreme simplification or greatly altered species diversity ("richness," relative abundance), either as a result of pollution and a factor in reduced resistance/resilience to environmental insult.
- Endangered Species and Habitats—loss of certain species and/or their habitats as a primary legal consideration.

Ecological studies over the past three decades, notably by the Odum brothers and their co-workers and by the staffs of such laboratories as Oak Ridge and Argonne National Laboratories, have established the interrelationship of these functions of ecosystems. Although the interrelatedness is not fully understood, we have begun to describe the connection between processes and components quantitatively.

Part of this process information is learned in the field; part comes from the laboratory. These processes are assembled into descriptive statements which, with proper assumptions, became interpretable as mathematical statements or models. As attempts are made to obtain parameters for these models, it has become necessary to perform experiments under the reproducible and controlled conditions of the lab. Moreover, there are a great number of processes about which very little is known. It is therefore desirable to study them as closely at hand as possible.

Single species assay tests for acute and chronic toxicity and the specific physiochemical measurements characterizing chemical processes in the abiotic environment were developed for screening pollutant problems. Dr. Robert Metcalf and his students and associates at the University of Illinois brought these approaches together (Figure 1) into a chemical test system mimicking some of the features of a "farm pond."[3] Several dozen chemicals have been tested in this system on behalf of the Federal Government, Food and Agriculture Organization (FAO), World Health Organization (WHO), and various companies (Table 1). The system is based on application of the chemical to sorghum grown in sand or soil. The plants are eaten by caterpillars which, along with any grass and debris, fall into the water or decompose on the sand. The aquatic phase then has short, constructed food chains of algae and other pond organisms leading to snails or a mosquitofish. By following the chemical and its transformation products to the terminal repositories, Metcalf *et al.* were able to set forth certain indices suggestive of problematic chemicals. Using the Ecological Magnification (EM) index—the ratio of parent chemical in the selected organism to that of the media, either soil or water—they have shown that the persistent and pervasive chemicals found in the field, such as DDT and other organochlorines, have very high EM values (greater than 3,000). Similarly, these same chemicals show very low Biodegradation Indices (BI)—the ratio of degradation products to residual parent compound—usually less than 0.03. Conversely, easily degraded and poorly accumulated chemicals have BI of over 1 and EM less than 1.

At the same time, one could make observations about the lethality or other toxic action of the chemicals. Even if quantitative statements could not be made, a "flag" might be raised for more specific determinations in side experiments. Therefore, organisms were selected for which the principles of the single species assay were generally established: easy rearing, known responses, and representativeness of various phyla to cover a spectrum of sensitivities and possible selective response. The physical environment was kept simple to minimize need for elaborate controls of complex situations which were not understood.

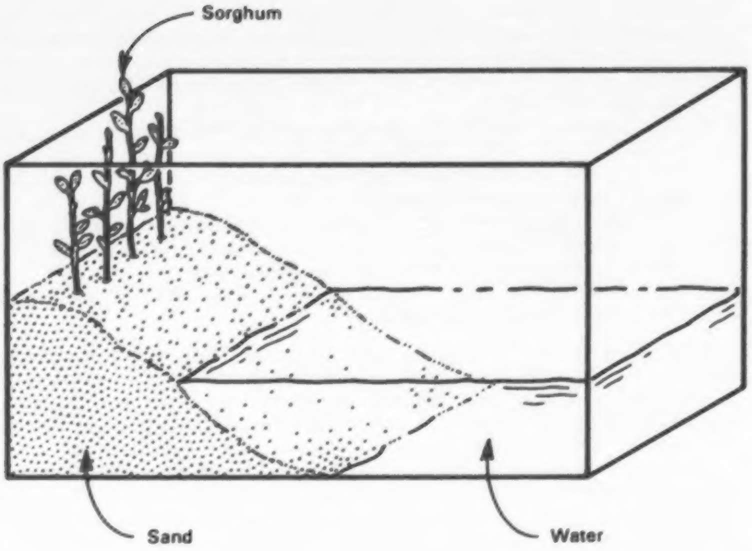


Figure 1. The system of Metcalf and coworkers[3] mimicking a "farm pond" is used to estimate bioaccumulation potential and biodegradation. Tank dimensions are 35 x 25 x 15 cm., with approximately 4 l. of water and 10 kg of sand. The water is innoculated with pond scum, sorghum (*Hordendum vulgaris*) is planted in the sand, and catepillars (*Estigme* sp.), *Daphnia* spp., snail (*Physa* sp.), and mosquitofish (*Gambusia* sp.) are added on a fixed schedule following treatment with radiolabeled chemical.

Although this system or its successors provide the only quantitative view of the environmental fate of chemicals in a holistic system, ecologists and many chemists have been reluctant to support the approach. The experiments are run without controls or replicates, and introduction of chemicals is artificial, as are the biological structure and trophic/energy relationships. There are practically no criteria for what could be termed a correct experiment. It has been argued that even the chemical fate in such experiments is out of scale in both time and space; partitioning between various compartments of the system may not be realistic.

Correct or not, the "Metcalf system" has sparked a variety of approaches similar in concept if not structure. "Model feedlots" with mice fed drugs were suspended over the aquatic system. "Rice paddies" were constructed to look at return flows from irrigation and runoff. Such flows have also been examined in "soil-plant" systems. Aquatic systems were improved in design to permit separation of predators (fish, crayfish) from prey (Daphnia). Some of the chemicals studied in these systems are shown in Table 2.

By the mid-1970s, about a dozen laboratories were developing such systems. Metcalf *et al.* focused on the terrestrial part of their system by using a "terrestrial monoculture" approach[5] which they then coupled to their aquatic system for a "physical laboratory model ecosystem" (Figure 2). In parallel, the "Terrestrial Microcosm Chamber" (TMC)[6,7] was developed in Corvallis and the "microagroecosystem"[8] (Figure 3) at Beltsville, Maryland. These involve at least an order of magnitude greater scale of the soil system and have somewhat different bases. The TMC system and microagroecosystem are both designed for chemical mass balance

Table 1. Chemicals Studied in Constructed Model Ecosystems

Chemical	System Type
DDT and related compounds, toxaphene, maneb, zineb, silvex, 2,4,5-T, heptaclor, heptaclor epoxide, endrin, lindane, DDD, chlordane, chlordene, trifluralin, and 8 other substituted nitroaniline herbicides, PCBs, TH-6040, TPTH, phenthoate	Micro-agroecosystem (T)
Stauffer N-2596, R-25788; phorate, eptam, fonofos	Soil-plant-water (T-FW)
HCB, mirex, 9 toxaphene fractions, 2,4,5-T, TCDD, trifluralin, oxadiazon, phosaline, atrazine and nitrosoatrazine, arsenical herbicides	Freshwater flow-through (FW)
Fenvalerate, DDT, BHT	Freshwater pond (FW)
BHC isomers, disulfoton, pyridaphenthion, cartap, edifenphos, Kitazin P®, PCP, CNP	Rice paddy (T-FW)
DDT, TCDD, mexacarbate, gamma-BHC	Freshwater pond (FW)
Dimethoate, fenitrothion, malathion, carbaryl, methomyl	Terrestrial-quail (T)
Alachlor, atrazine, bentazon, cyanazine, dicamba, phenmediphan, 2,4-D, propachlor, pyrazon, trifluralin, metrabuzin, bifenox, chlorpyrifos, chlorpyrifos-methyl, Counter®, Temephos®, fenitrothion, malathion, acephate, leptophos, parathion, metalkamate, carbaryl, carbofuran, propoxur, aldicarb, formetanate, methoprene, dimilin, chlordimeform, Banamite®, DDT, DDD, methoxychlor, and 8 halo-alkyl substitute DDT analogs, aldrin, dieldrin, toxaphene, endrin, lindane, mirex, heptachlor, chlordane, hexachlorobenzene (HCB), pentachlorophenol (PCP), endosulfan, methyl parthion, benzo(*a*)-pyrene, benzidine, vinyl chloride, anthracene, fluorene, carbazole, dibenzofuran, dibenzothiaphene, ethylhexyl phthalate, triphenyl phosβhate, polychlorinated biphenyls (PCBs)	Farm-pond (T-FW)
Robenine-HCl, ddt	Feed lot (T-FW)
Methyl parathion, atrazine, carbaryl, pentachloronitrobenzene (PCNB), propanil, mephosfolan	Rice paddy (T-FW)

Table 1. Continued

Chemical	System Type
Methoxychlor, DDT, fonofos, aldrin	**Terrestrial monoculture (T)**
Dieldrin phorate, HCB, PCNB, PCP, captan, 2,4,5-T, simazine, trifluralin, methyl parathion, parathion	**Physical model ecosystem (T-FW)**
Dieldrin, methyl parathion, parathion, p-nitrophenol, HCB, PCP, PCNB, 2,4,5-T, captan, simazine, bromacil, trifluralin	**Terrestrial microcosm chamber (T)**
Dieldrin, bis-tributyltin oxide, PCP, creosote (phenanthrene, acenaphthene)	TMC (T)

TABLE 2. CHEMICALS STUDIED IN EXCISED MODEL SYSTEMS[4]

Chemical	System Type
Dieldrin, 2,4,5-T, methyl parathion, HCB	5 × 10 cm soil core
Sodium arsenate, HCB	5 × 10 soil core
Methyl parathion, carbaryl, PCP, dimilin	Eco-core (Estuarine)
Pb, Cd, Zn, Cu	Large soil core
DDT, Cd, toxaphene, Aroclor 1242	Freshwater pond
PCBs, DDT, and related compounds, HCB Clorpyrifos, dieldrin	Freshwater Pond
2,4-D, CIPC, monuron, atrazine	Freshwater pond
HCB, bis-(ethylhexyl)phthalate	Benthic bucket

studies, but the latter contains only soil and plants. Both the TMC and the Metcalf terrestrial systems contain a *Microtus* species of field mouse as the highest terrestrial consumer.

These new systems permit temporal and spatial analysis of chemical fate. However, the biological facets of toxicity are still simply "flagged" by observations of an anecdotal nature. It is hard to obtain statistics on a single vole in a system. Moreover, the vole causes considerable destruction, digging up the soil and consuming all or most of the other biota. The animals leave "elephant tracks" through the system. In spite of these difficulties, the systems behave consistently upon limited replication and generally agree with available data on chemicals in the field. Clearly these microcosms are better for providing chemical fate data than ecotoxicological information.

During the last part of the 1970s the pressures of impending legislation regarding toxic substances and for a more incisive approach to evaluation of pesticides and hazardous wastes began to be felt by both regulatory agencies and the chemical industry alike. The techniques useful for studying pesticides and drugs were too resource-intensive and sophisticated to be applied across the board to a hundred times as many chemicals. Laboratory model ecosystems or microcosms offered what

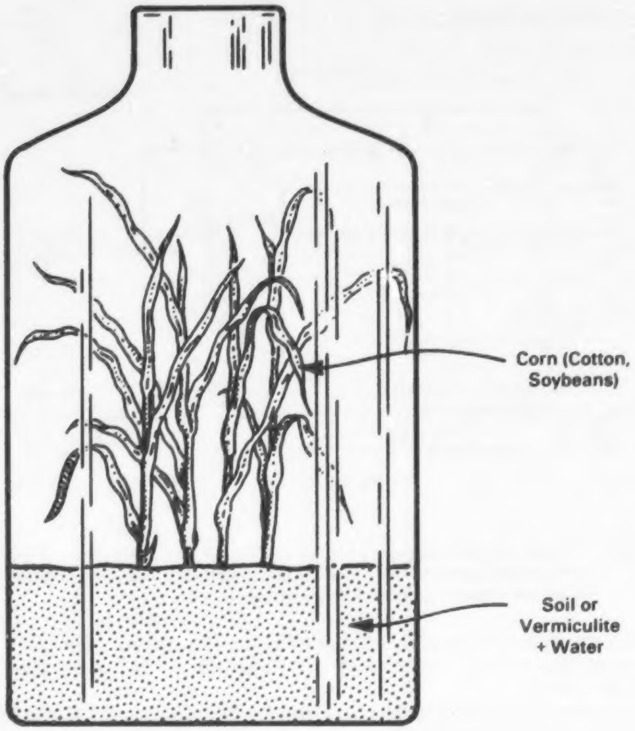


Figure 2. The "terrestrial monoculture" system of Metcalf and coworkers[5] employs a crop grown in soil or vermiculite in a 19-l. carboy and additions of slugs, insects, and a Prairie vole (*Microtus ochregaster*). Subsequently, the terrestrial species are removed and analyzed, while the system is flooded and then innoculated as for the "farm pond." Additions of *Daphnia*, snails and *Gambusia* are analyzed after three days, then the water is drained to estimate soil/sediment sorption.

seemed to be a reasonable alternative. Natural resources could be protected by foregoing testing in the field. Systems could be replicated and operated under controlled, standardized conditions, much as are single-species assays. A number of advocates pointed out so many advantages, in fact, that expectations easily exceeded achievements.

Nevertheless, when the terrestrial microcosms were reviewed by chemists, biologists, mathematicians, and regulators in 1977,[9] they found that research did support a number of positive values of microcosm technology.

- Fate and effects studies can be carried out simultaneously in the same system to provide a more meaningful measure of dose-response in a system reflecting interactions of processes;
- The systems are more easily replicated and controlled than field studies, yet they still yield data on ecosystem function;

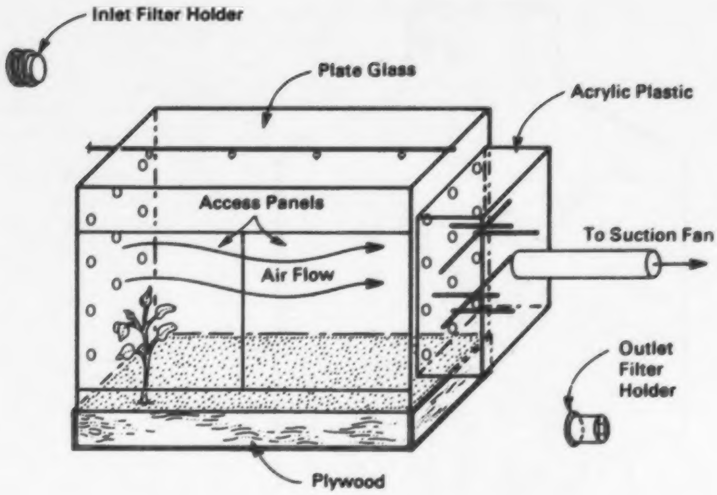


Figure 3. The microagroecosystem of Nash and Beall[a] is a large (2 x 1.5 x 0.5 m) monoculture of crop or grass without added fauna. Trapping of material at outlet contributes to mass balance studies.

- Microcosms can be adapted to specific situations involving a chemical, site, crop, or impacted species/community, without loss of the basic character of the ecosystem;
- Microcosms can be structured by not only the physical system but also by the use of "expert judgment" to frame research questions in an optimal manner;
- Multimedia interactions and disposition are evident particularly for bioaccumulation and intermedia transfer rates;
- The systems provide greater realism, both objectively to the scientists and subjectively to the lay person, than do laboratory tests and are therefore more persuasive regarding the relative hazard or safety apparent from the data.

At the same time it was necessary to point out several problems:

- Microcosms are not self-sustaining.
- Criteria do not presently exist to determine what factors of scale in time and space are significant for a particular kind of information.
- Criteria have not been established for the accuracy of microcosm data with respect to real ecosystems. Can they be generalized or do they simply represent only some special system (if that)?
- Requirements for radioactive chemicals in fate studies, for special material and operating controls, and for skilled technical personnel at all levels limit how and by whom these systems might be used.
- Except for one system, none of the microcosms has been defined in the explicit terms of a mathematical model which can provide extrapolation to other situations.
- Ecological theory and research have not defined processes adequately, so that their study application in microcosms is generally restricted.
- Serious questions remain about such matters whether or not larger organisms (e.g., the field mouse, fish or crab) can be included in these systems.

While research was proceeding apace with assembled systems such as the Metcalf farm pond and the TMC, significant strides were being made with excised systems for ecological effects. As noted above, these have been confined largely to inorganics rather than toxic organics, and studies have focused on decomposition, respiration, nutrient cycling, primary productivity, and, to a lesser degree, community structure and spatial composition. Both aquatic and terrestrial microcosms have been developed.

The simplest excised terrestrial system is the soil core microcosms (SCM) which may have a variety of configurations (Figure 4(a)). A core is plugged from the soil, with or without removing surface vegetation, and immediately attached to a funnel and support to collect leachate. The leachate contains nutrients and trace minerals and reflects the status of the soil community. Excessive loss of nutrients such as calcium, phosphate, and nitrite/nitrate upon exposure to a toxicant would indicate loss of community integrity and is frequently seen in the margins of ecosystems severely damaged by mining, smelting, etc.

Van Voris and co-workers at the Oak Ridge National Laboratory[12] performed very significant experiments with cores (Figure 4(b)) from a fescue meadow. Encasing the top with a plastic chamber, they recorded carbon dioxide concen-

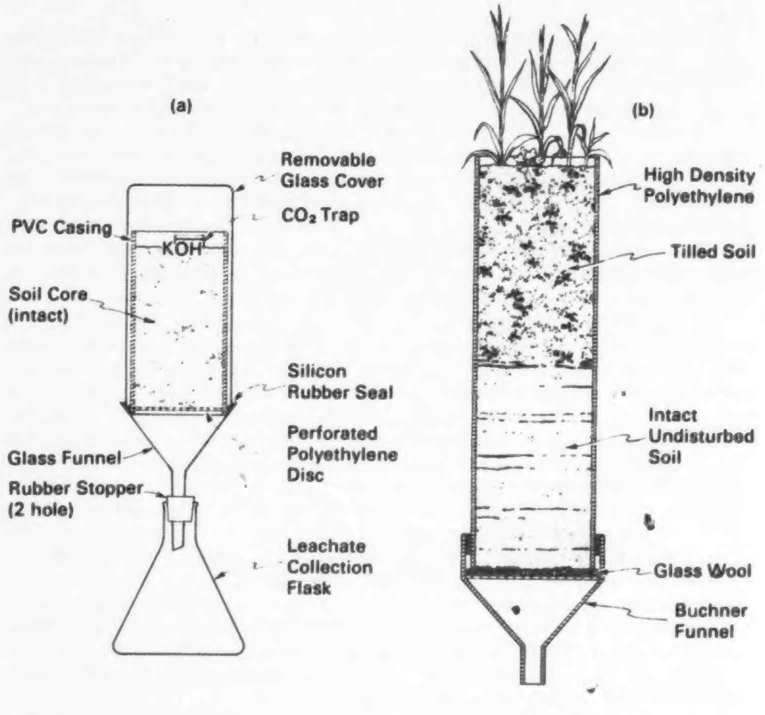


Figure 4. Excised soil core microcosms (SCM)[10] have been prepared that are (a) 5 cm (d) x 10 cm (l), and (b) 15 cm x 30 cm.[11,12] These may contain indigenous flora and fauna or be prepared from bare soil. Total CO_2 evolved or CO_2 concentration is used to follow respiration while the nutrient loss is measured in leachate.

trations hourly and leachate contents weekly for 175 days. After 90 days they treated all but two systems with cadmium chloride, a known soil poison. Prior to treatment leachate nutrient loss had stabilized. The addition of cadmium greatly stimulated loss of calcium and other nutrients, which then gradually returned to normal (pretreatment) values.

Using standard ecological procedures, they examined plant species diversity and richness and analyzed residual nutrients in each microcosm. Through computer time-series analysis of the carbon dioxide data, they found patterns of peak frequencies of carbon dioxide flux inversely correlated with the extent and duration of excessive nutrient loss. The microcosms with the greatest diversity, as revealed by the carbon dioxide analysis, were most resistant and resilient; those with the lowest diversity were most vulnerable and least resilient. Although predicted by ecological theory, this relationship of ecosystem complexity to functional stability has seldom been quantified so clearly.

This study also demonstrates the superior role that microcosms can play in probing the effects of pollutants under precisely controlled conditions. This experiment could only have been performed in a laboratory. Even though technically sophisticated, the approach is actually fairly simple. The process can be measured with inexpensive, widely available equipment and does not require highly skilled personnel. The technique could be applied to any given chemical or site that might be impacted.

A host of excised aquatic systems have been studied for each of the several major types of ecosystems: lake, stream, estuary, and marine environment. Some systems include the sediments; others concentrate on the water column. The simplest is the estuarine Eco-core microcosm developed by the scientists at the EPA laboratory at Gulf Breeze, Florida. It functions much like the smaller soil core systems, both in terms of results of chemical metabolism and in the role it can play in evaluation. Larger systems have been employed by the Narragansett and Corvallis EPA labs independently to examine community structure and impact of pollutants from dredging and ocean dumping of sludge, etc. The largest microcosm is the 11,000-gal. Marine Ecological Research Laboratory (MERL) system in Rhode Island, which has been employed for studies of both scale and complexity regarding microcosm structure and the impact of petroleum on marine organisms.

Several significant freshwater systems of diverse scale are also in use or have been employed extensively over the past decade. The laboratory stream of Charles Warren[13] and colleagues is a simple double channel connected at each end by a paddlewheel to provide movement and aeration of water (Figure 5). This type of system has been useful in examining problems as diverse as effects of logging on forest streams, impact of pesticides on intra-species and inter-species community species structure, and toxicity of pulpmill wastes to anadromous fish. Other stream systems of note are the multiple channels at the Savannah River Ecology Laboratory in Aiken, Georgia. The Monticello, Minnesota channel is being used by scientists from Michigan State University and two EPA labs to validate the Exposure Assessment Model System (EXAMS)[14] developed at the Athens, Georgia EPA lab over the past several years. The EXAMS model can be used to predict chemical concentration of a pollutant based on the loading or input of the chemical into a stream, pond or lake. Such predictions are of great utility in comparing single-species responses from laboratory studies to concentrations the test species might encounter. EXAMS was derived in part from studies in the pioneering Artificial Ecosystem Simulator (AECOS) model stream at Athens.

Important studies on the criteria which might be employed in evaluation of microcosms have been carried out at the Oak Ridge National Laboratory, Tennessee, and Lawrence-Berkeley, California, Radiation Laboratory (LRL). These studies have addressed very serious questions and problems that have plagued researchers since they first began developing laboratory systems for evaluation of pollutant

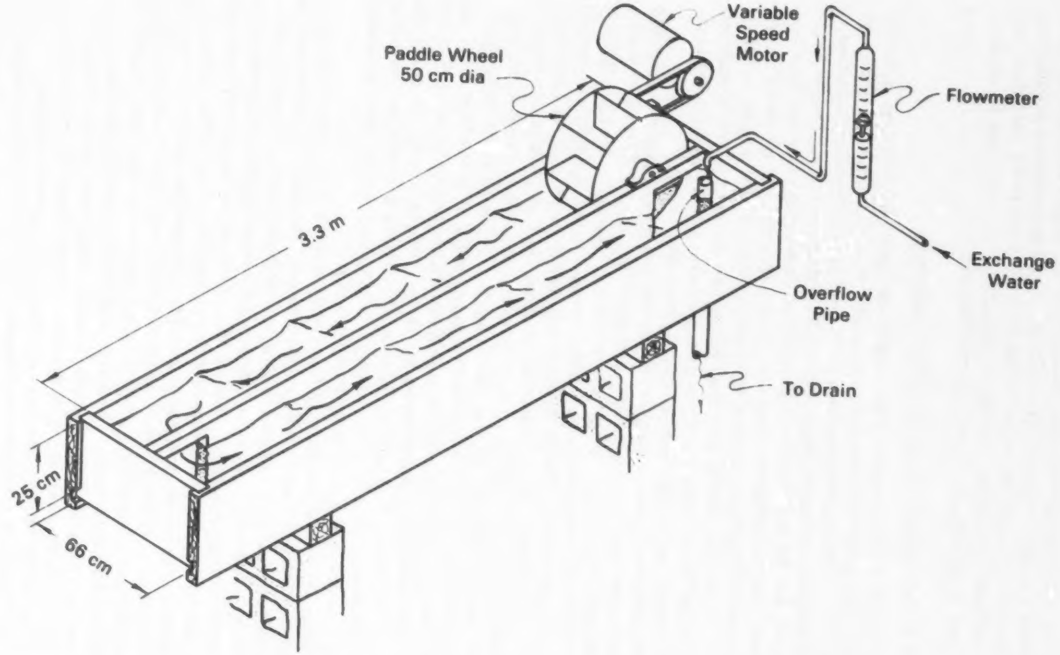


Figure 5. The double channel laboratory streams of Warren and Davies[13] have a rock, litter or sediment substrate with water circulated by paddle wheels at each end. They are operated in either a flow-through or contained mode, with natural or introduced invertebrates, and with adult or juvenile salmonids.

impacts on freshwater bodies. Both labs found that inclusion of larger organisms (beyond zoo- and phytoplankton) prevented the systems from replicating nutrient cycles and system stability of natural bodies of water. LRL scientists have overcome troublesome features of most aquaria—the growth of dense algae mat at the surface—by simply pouring or siphoning the water periodically. Stable systems that are reproducible and track representative bodies from which they were derived have thus been operated for up to about 60 days.[15] These would be more than adequate to determine short-term effects of a particular kind of wastewater treatment on decomposition functions and community composition, but could not be applied directly to longer term matters, such as fisheries impacts.

Application of Laboratory Ecosystem Measurements

The characteristics of ecosystems are expressed through processes reflecting structure and composition. Measurement of process rates in the laboratory becomes a significant probe of these same processes in the field. One of the most important of ecosystem processes evaluated through both model systems and the real world is that of bioaccumulation. We have come to regard this outcome of the various competing chemodynamic and biodynamic processes as an indicator of potential threat. Clearly, if even simple microcosms had been used before the introduction of DDT, dieldrin, and PCBs, we would have recognized the propensity for widespread contamination of biota, transfer of residues between media, and the resultant ubiquity accompanying the persistence of such chemicals.

Although a tendency to accumulate in fatty tissues can now be partially predicted by simple laboratory tests (partition coefficient, solubility, etc.), only in the complete system is the actual outcome of the interactions of volatility, biodegradability, adsorption, and other processes realized. Before moving to the field to test a group of candidate mosquito-controlling insecticides, the WHO contracted to have them tested for environmental fate in model ecosystems. Bad actors were revealed in advance of any threat to wildlife.[2] Even though no microcosm test is currently accepted as standard, indices such as the Ecological Magnification or Biodegradation Index may be the only experimental verification of predictions from the simpler laboratory tests. Because bioaccumulation studies are so expensive, EM and BI provide the substantive justification for further testing needed by either the developer or regulator of a toxic substance. Employing a model ecosystem in chemical mass balance studies gives us confidence in using simpler tests, or reveals gaps that are unanticipated from simple relationships.

This degree of understanding, carefully compared to field results, leads to mathematical statements and models. Such efforts as EXAMS have evolved considerably from microcosm studies. The use of computers can thereby bring single species toxicity data into exposure assessments. By comparing anticipated exposures with known toxicologic data, safety margins can be introduced as part of planning in municipal water supply and wastewater treatment, permit writing for discharges, etc.

Although microcosms are currently employed most advantageously in examining chemical exposure, fate, and bioaccumulation, the success of Van Voris *et al.* noted earlier has helped to crystallize ecological theory on the relationship of functional complexity to ecosystem stability. The potential for further exploitation of ecological theory is most promising. For example, benthic model ecosystems have probed potential problems of community structure resulting from oil spills and ocean dumping. Freshwater microcosms can suggest which treatment technology or land management practice is least likely to damage nutrient cycling and decomposition processes, so fundamentally important in sustained yield for fisheries. Higher order interactions between species, populations, and communities may be more sensitive to effects of chemicals than single species developed as bioassay standards. Conversely, microcosms may be developed which demonstrate the stability of systems well within the currently envisioned safety margins, thus making more precise management possible. An active search for such features is of considerable importance to both industry and regulatory agencies.

These types of applications are occurring now, even though no system or set of systems has been endorsed as a standard. Expert judgment and careful use within acknowledged limits are necessary at present and for the foreseeable future. However, as the relationships between the single species, physiochemical, model ecosystem and field tests are more clearly understood and defined through standardization and criteria development, microcosm technology may yield to structure—activity relationships from powerful computerized data bases. Thus, it will serve as an intermediate technology, both in form and function.

LOOKING TO THE 1980s

Several lines of research are currently being followed in concert. Part of the functions of microcosms are transient, in that we expect them to lead us to tools that benefit from the simplest and least expensive measurements possible. These would include "screening microcosms" for rapid assessment of community and ecosystem disruption or for parameterization of mathematical models. Benefits of cross-pollenization from diverse approaches by different agencies and industries have already emerged.

The most important on-going research is that which provides criteria of a system's validity with respect to (a) the real world, (b) inter-laboratory replicability, and (c) relationship to simpler tests. Establishment of these criteria will then provide means of standardizing operations and interpretation. Achieving these criteria will greatly expand opportunities for investigation of critical ecosystem functions in the microcosm, as a research arena or "field in the laboratory." Questions of physical scale, biological complexity, and whether or not macrofauna may be included will be determined by such criteria. Until these criteria are set forth, microcosm technology will be subject to understandable skepticism.

Microcosm systems are presently just getting away from the need for extensive and sophisticated laboratory support. It is unlikely that chemical measurements will become less costly in the future, but automation of ecological tests and control of environmental conditions can be anticipated. These advances, coupled to defined criteria for evaluation, can lead to better systems for specific site studies and for generic investigations of ecological processes alike.

The regulator will continue to seek the ideal microcosm(s) which can be used to test literally thousands of chemicals and real world situations. The research will examine variations in structure and response of a large number of systems to a small group of chemicals, mainly in attempts to understand the world. Success to date tantalizingly hints that both may have their wish, but only if short-term gains can continue to justify the cost in manpower, laboratory space, and other scarce resources. This realistic economic need is well recognized (as if the scientific problems were not enough of a hurdle), so that the first half of the decade is a critical period in the future of microcosm technology.

Part of that future rests in the overall plan for completing the evaluative bridges through the swamp of chemical and pollutant regulation. Microcosms are presently seen as peripheral to early steps within most assessment schemes. Application in confirmatory and exploratory stages, particularly where microcosms might substitute effectively for multiple tests or elaborate field studies, would mean that they have become part of the piers of bridges, cutting short the distance to our goal of rapid, accurate, and cost-effective assessment.

REFERENCES

1. Kallet, A., and F. J. Schlink. 1933. 100 Million Guinea Pigs. Vanguard Press. New York, N.Y. 210 pp.

2. Neuhold, J., and L. Ruggerio. 1976. Ecosystem processes and organic contaminants. NSF/RA-76-0008. National Science Foundation. Washington, D.C. 44 pp.
3. Metcalf, R. L., G. K. Sangha, and I. P. Kappor. 1971. Model ecosystem for the evaluation of pesticide degradability and ecological magnification. Environ. Sci. Technol. 5:709-713.
4. Gillett, J. W. 1981. Model ecosystems in fate and movement of toxicants. pp. 214-232. *In* Test protocols for environmental fate and movement of toxicants. G. Zweig and M. Beroza, eds. Association of Official Analytical Chemists. Arlington, Va.
5. Cole, L. K., and R. L. Metcalf. 1979. Predictive environmental toxicology of pesticides in the air, soil, water and biota of terrestrial model ecosystems. pp. 57-74. *In* Terrestrial microcosms and environmental chemistry. Witt, J. M., J. W. Gillett, and C. J. Wyatt, eds. NSF/RA-79-0028. National Research Foundation. Washington, D.C.
6. Gillett, J. W., and J. D. Gile. 1976. Pesticide fate in terrestrial laboratory ecosystems. Intern. J. Environ. Studies. 10:15-22
7. Gile, J. D., J. C. Collins, and J. W. Gillett. (in press). Fate and impact of wood preservatives in a terrestrial microcosm. J. Agric. Food Chem.
8. Nash, R. G., and M. L. Beall, Jr. 1979. A microagroecosystem to monitor environmental fate of pesticides. pp. 86-94. *In* Terrestrial microcosms and environmental chemistry. J. M. Witt, J. W. Gillett, and C. J. Wyatt, eds. NSF/RA-79-0028. National Science Foundation. Washington, D.C.
9. Gillett, J. W., and J. M. Witt. 1979. Terrestrial microcosms. NSF/RA-79-0034. National Science Foundation. Washington, D.C. 41 pp.
10. Draggan, S. 1976. The microcosm as a tool for estimation of environmental transport of toxic materials. Intern. J. Environ. Studies. 10:65-70.
11. Van Voris, P., M. F. Arthur, and D. A. Tolle. 1981. Field and microcosm investigations of the effects of atmospheric deposition from fossil fuel combustion. RP1224-5, Report from Battelle Columbus Laboratory to Electric Power Research Institute. Palo Alto, Calif. 176 pp.
12. Van Voris, P., R. V. O'Neill, H. H. Shugart, and W. R. Emanual. 1980. Functional complexity and ecosystem stability: an experimental approach. Ecology. 60:1300-1324.
13. Warren, C., and G. E. Davies. 1971. Laboratory stream research: objectives, possibilities, and constraints. Ann. Rev. Ecol. Systems. 2:111-144.
14. Burns, L. A., D. M. Cline, and R. R. Lassiter. 1980. Exposure analysis modeling system: user manual and system documentation (draft). Environmental Research Laboratory, U.S. Environmental Protection Agency. Athens, Ga. 440 pp.
15. Harte, J., D. Levy, J. Rees, and E. Saegebarth. 1980. Making microcosms an effective assessment tool. pp. 105-137. *In* Microcosms in Ecological Research. J. Geisy, ed. DOE Symposium Series 52. Technical Information Center, U.S. Department of Energy. Washington, D.C.

MITIGATION AND MANAGEMENT OF DAMAGED ECOSYSTEMS OR DAMAGED HABITAT: OVERVIEW

Robert H. Giles, Jr.

Nature is a mitigator. When a tree falls, it is replaced. When an oxbow of a stream overflows, a new channel is created. The old channel is reformed so that, without much effort, it can be imagined that a lake is traded for a stream. Rarely are such natural processes considered mitigation. Rather, they are seen as replacement, growth, and successional phenomena. Mitigation has taken on some very special legal and regulatory connotations. But before discussing these, it is useful to remember and rethink the major natural mitigation forces at work. By understanding this concept, it may be possible to not only see damage more clearly but also to establish a standard for determining how bad (or well off) things really are. For example, a particular phenomenon which we observe may be judged "bad." If we see it occurring naturally, and can also see what changes follow the event, we can then better answer questions about "how bad" and about reasonable expectations for recovery.

There are some amazing things happening in nature: prolonged drought, volcanic eruptions, floods, creation of lakes from earth slides, forest fires, tornadoes, ice storms, and massive insect outbreaks. These are all natural phenomena, which probably occurred before people were around. They cause major changes in ecosystems and habitats where animals (including people) live. An interesting aspect of all of these ecosystems is that none is static. All undergo drastic change. These changes are often grouped under the concept of succession. This means, briefly, that there is a series of identifiable, quite predictable, stages through which every new body of water, bare rock, or clear land will go. In the eastern U.S., for example, the stages often consist of mosses, small plants, softwood trees (e.g., pine), and finally hardwoods (e.g., oaks). Each part of the country, each biome, has its own successional pattern. Each biome has quite different rates of succession. The changes are very much a function of solar energy, temperature, and moisture.

Catastrophe and change are natural. Sickness and death of plants and animals are natural. Almost all wildlife have high parasite loads and latent disease organisms. The concerns voiced about the environment are not about natural changes alone but about a variety of new causes of change, new rates of change, the sequences of the changes, and their interactions.

Before discussing each of these, it is important to get a good grasp of the concept of "damage." It is an ambiguous word and failure to understand it can lead to some very peculiar conclusions and strategies of action in the name of mitigation. Damage is any physical change in a resource or part of an ecosystem that has significant detrimental effects to a particular group of people. Damage includes Injury plus Negative Valuation. There are many consequences of such an understanding, a few of which are:

The Author: Dr. Giles is Professor, Dept. of Fisheries and Wildlife Services, Virginia Polytechnic Institute and State University at Blacksburg. He has worked as a biologist in Virginia, and taught big game management at the University of Idaho. His teaching and research at Virginia Tech concerns computer systems for planning power line, mine reclamation, airport site location, watershed, and forestry land uses.

1. Injury may change overnight to damage when a group becomes aware of resource and perceives its loss or change harmful to their interest,
2. Damage to one group of people may not be damage to another; in fact, there may be benefits.

This last statement may not be clear. Like pain, a little damage may be very beneficial for it can prevent further major damage. A little pain may be instructive, a lot of pain deadly. Similarly, as in a cotton insect outbreak, the cotton loss may be great in one area but the cotton prices may double for someone else. It is possible that some insect control programs (said to be damage control but in practice usually injury control) may allow high crop production, lowered prices due to simple supply-demand relations, and a net monetary loss to the farmers and the national tax base. Damage is easy to claim and hard to compute.

Management means operating a rational system for achieving human goals or objectives. An example of the role of resource management is shown in Figure 1. In the unmanaged state, elk (e.g., in the Pacific Northwest, USA) waxed and waned as forests matured and fires burned. Elk need low-growing grass, forbs, and browse (i.e. twigs and leaves). Elk populations peaked when food supplies (resulting from lightning fires) were abundant. They usually over-grazed and browsed their range, eating away their food supply, and the future populations suffered or were never born due to low nutrition. These are the low points in Figure 1. This unstable population with its sharp peaks and troughs was natural. Under management, as shown, a desired population can be achieved, preventing the highs (when forest tree damage, soil erosion, and trout stream losses occurred) and the lows (when hunting is poor and starvation conspicuous).

Management means steering the resource ship, within bounds, to reach a desired destination. The destination has to be decided by people. Simply being at the rudder without direction does not count, for that will probably lead to a course much like that produced by nature.

It may seem heretical to some, but natural trends may not be most desired by people. The odds are they are not. Controlling and shaping a resource, much as in Figure 1, is necessary if the very undesirable highs and lows are to be avoided.

Sometimes these highs and lows *cannot* or will not (a clear decision) be avoided. Then society or some group pays. Mitigation is payment. It is one of the last of the

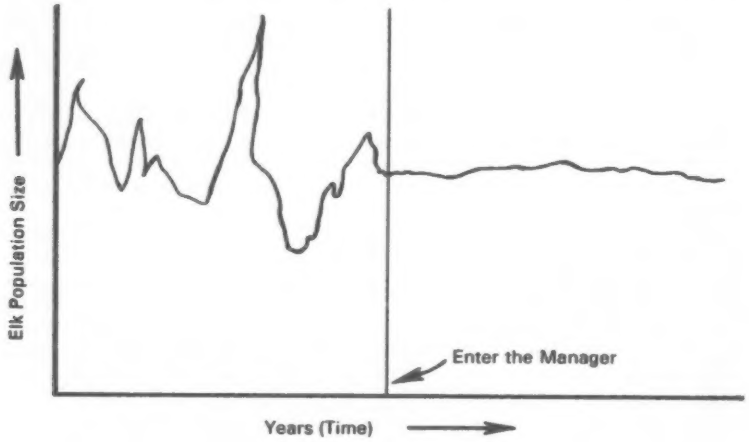


Figure 1. Graph of elk population.

managerial alternatives. It is, from one point of view, a signal that other managerial tactics and strategies have failed. Typical mitigation efforts are: (1)purchase of and dedication of equivalent land to that which is covered by a dam and its lake; and (2) stocking of fish from hatcheries to replace those no longer produced naturally.

Mitigation is as natural to resource management as surgery is to a progressive health system. Management includes manipulation of people's concepts, ideas, knowledge, and values through broad-scale environmental education. It includes legal activities to prevent and control harmful actions (e.g., penalties), to encourage other actions (e.g., tax incentives). It includes public participation in decisionmaking, partially as an educational process, and partially as a means to elicit expressions of group values. It includes direct habitat manipulation, usually aimed at speeding or retarding ecological succession through the so-called action checklist: forestry (cutting, planting, crushing, and herbicides); farming (burning and blasting); flooding (including irrigation and drainage); fertilizing; furnishing (nests, dens); feeding (direct and grazing); and fencing (in or out).[1] It includes timing of activities (e.g., flood water or irrigation releases), creation of new habitats (e.g., an island for the Hawaiian stilt), and movement of animals, including stocking and transplants. Management also includes direct manipulation of the resource. In the case of wildlife it may include control of many aspects of the hunt,[2] stocking and transplanting, and changing mortality as well as reproductive factors. Genetic manipulation may have later potentials.

We have noted the heightened concern about certain environmental changes. These concerns reflect the emergence of new groups and their awareness of damage, a need for more powerful managerial systems and for more mitigation. In addition, there are compounding issues — new changes, new rates, higher risks, sequence problems, and, as if that were not enough, their interactions. These issues will be briefly noted so that they will be clearly visible in the following papers in this section.

New changes are a result of more people with more energy and more technology. The U.S. remains a place of growth; cities, industries, and farms expand. There are signs of slowing but they are vague. New substances, new machines, new forestry practices, new cultivation, new industry — ; the rates of change are very rapid. There is little time for managerial adjustment, either to the processes or human values. There is no time for ecological adjustment. Evolutionary processes are ponderous; recent human processes are precipitous.

The scale of change is cause for concern. One falling tree leaves an opening that is quickly filled in. It is as if things had been readied for the fall; the system was in wait. The clearing of 50 acres for a factory is no mere tree-fall. The site will not "fix" itself; nothing is in wait. Of course, it will eventually be restored. But will people be able to tolerate that condition for the required time? It is too unpleasant and too costly. Through management, the successional processes can be speeded. Certain areas need not be leveled. Long-term work with the ecosystem of the factory becomes the new realization. A one-time get-in, build, fix it, and leave-the-lawn policy, good in a few places, is not a satisfactory universal answer. The simplest rule in ecosystem management is that there are no simple rules. Complex systems of human importance deserve management suitably complex and sophisticated to reduce costs and risks.

Risks are not discussed much but they are at the heart of managerial concern. An engineer may plan a dam for a 100-year flood. If he discovers rainfall patterns have changed and he gets such a water volume every 10 years, he will be distraught (or sued). What is distressing among the massive changes taking place around the country is that these types of unexpected behaviors are occurring. Paved over watersheds no longer retain as much water. New irrigation places whole communities at risk of water shortage. New local climates and water temperatures put local groups at risk. Part of the risk concept is the frequency of damage, and part is the magnitude of damage. Another part, one not easily quantified, is fear and how it relates to the quality of life. It is not necessary to be able to measure adrenal levels of people living near a potential catastrophe, one not of their choosing, to prove that local stress has reduced or will reduce group life expectancy. In a human society where damage is seen as having an environmental as well as a human value dimension, it is important to minimize risk—at high cost— because we are human.

The faster that change is made through industrial development, power and utility lines, off shore development and so on, the less are the managerial opportunities—either to discover or execute controlling processes to keep the ecosystem on course. In some biomes natural change is very slow. To move a community through management to some more desirable stage of succession is very expensive or nearly impossible.

It is virtually impossible to jump a state of succession. Managerial efforts, though well-intended and well-funded, may not succeed. For example, certain soil and root structures are needed before certain plants will survive. Planting and caring for plants may not assure their survival if the right conditions do not exist. The soil must have achieved a particular stage—largely through a series of complex plant, water, animal, moisture, temperature, and chemical interactions. Like human healing, land healing cannot be bought. The development of an ecosystem may be enhanced, but there are limits. Humans must wait. Waiting, while change and risks seem to accelerate, is not pleasant; it produces fear in those concerned for themselves and their children.

The Earth seems more finite now that people have traveled to the moon. This realization raises questions about the concept of mitigation based on replacement. A wildlife area is lost; it is replaced elsewhere. This concept grows out of an earlier view that land and energy were inexhaustible. In looking at sites for dams, it is clear there is a limited number of sites. Dams have already been built on many of the better ones and are proposed for many others. No matter how desirable are the benefits from the dams—fishery recreation, electricity, water supplies—we shall use up all the feasible sites. In very much the same vein, there is only a limited amount of land on which food can be cost-efficiently produced for people.

Indeed, all land is not equal. In recent court proceedings involving flooding from a planned dam project, "acres" were in question, rather than "functional acres." Mitigation would have somehow replaced acres for acres. In the particular case, the flooded area was the nesting and brood site for a vigorous wild turkey population. Although thousands of acres inhabited by turkeys would not be inundated, the key areas were to be flooded. They were the heartland for the turkey population. Mitigation action, if it were possible, would somehow have to replace in like kind and amount areas for nesting adjacent to brooding areas (with high insect populations) near mature hardwood forests. Not only the *amount* of land for mitigation is crucial. Other factors such as the *sequence* and the *management* and the dependability (*risk*) in reproduction over time are all interactive.

In the following chapters there emerges a complex tale of other interactions. Some ecosystems are purposely injured (Figure 2). Damage is experienced by some people—benefits by others. The long-term question for national policy, laws, and public processes is for how to assure that there is a net, long-term benefit. Some damage is inevitable in any major action involving the land, water or air. Balancing the total, weighted risks, benefits and costs is the challenge for the future. The complexity of the problem can only be matched with computer assistance.

There are already means to characterize ecosystems and their processes and indices to their value to humans. Computers can provide a look at the likely changes that will occur if a particular complex action is taken (e.g., building a power generation facility and transmitting its product across the land). OBS has supported a program to locate powerlines to minimize ecosystem damage. There is no one best place, no best action; there is only the *least bad* place or action. All actions modify ecosystems or have costs. Attaining the bad and least costs are the emerging concepts for management and mitigation.

Often, no action is the best action. Ecosystem managers may have to spend great amounts of agency and personal time and energy to prevent action. Wilderness

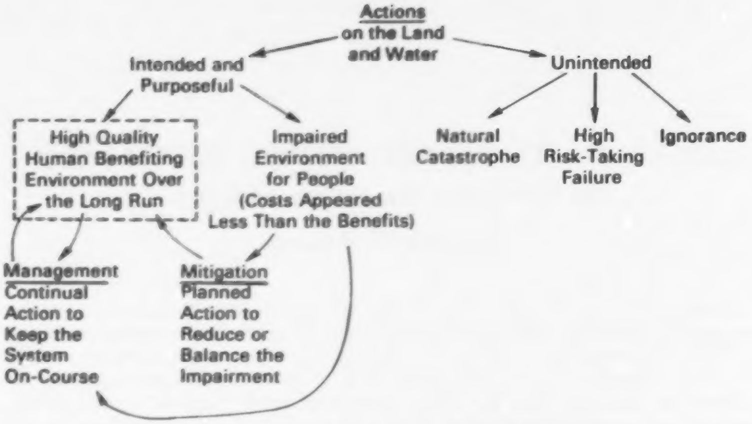

Actions on the Land and Water
Intended and Purposeful
Unintended
High Quality Human Benefiting Environment Over the Long Run
Impaired Environment for People (Costs Appeared Less Than the Benefits)
Natural Catastrophe
High Risk-Taking Failure
Ignorance
Management Continual Action to Keep the System On-Course
Mitigation Planned Action to Reduce or Balance the Impairment

Figure 2. Chart of actions on the land and water.

preservation is one conspicuous example. But even *not* cleaning up oil slicks in certain areas may be the best strategy. The managerial task is to know natural processes well enough to be able to decide whether they can be augmented, or whether time and sequence are the forces that will produce the greatest total human benefits from ecosystems over the long term.

Figure 2 shows the major pathways displayed by the authors in this section. Only through research, improved decisionmaking, applications of existing knowledge, and preparation for catastrophe can the human actions be shifted to the left of Figure 2. Ignorance can be alleviated by education and practices changed by public behavioral modification but there appear to be real limits. Indeed, we have had massive educational programs in conservation and natural resources since the turn of the century. Some of us worry whether there is time enough to reduce widespread ignorance of ecosystems and to prevent such ignorance from destroying us. Ignorance will destroy or impair some ecosystems. Thus, laws and more obvious limitations on human activity (fences, etc.) will be needed. High risk taking activities such as building on flood plains, solid waste disposal on improper soils, and over-use of groundwater will and already have impaired other ecosystems.

Impaired ecosystems can often be repaired, but at great monetary cost and with massive foregone benefits and a sense of loss of quality of life. There emerges within many resource managers faced with mitigation and restoration of ecosystems that their work can never be done right. A project is not completed before a start must be made on another one. Rarely is one restored; the resources are too limited; the new cases arise daily. There is only the sense of living among partial ecosystems—those that are scarred or disfigured, surviving never whole. These are not the kinds of ecosystems fit for humans. While ecosystems can be repaired, and some losses mitigated, the overriding concepts herein are aimed at reducing the need for mitigation. The message: sensitively manage, manipulate, and care for ecosystems so they may serve people well now and in the future. Incur benefits, not costs.

REFERENCES

1. Giles, R. H., Jr. 1978 *Wildlife Management.* W. H. Freeman Co. San Francisco, Calif. 416 pp.
2. Giles, R. H., Jr. 1971. Wildlife conservation and wildland operations research. pp. 560-567 *In* Encyclopedia of Science and Technology. McGraw-Hill Co. New York, N.Y.

WILDMIS - A SYSTEM FOR ESTIMATING THE COST TO REMEDY HABITAT LOSSES

Kenneth R. Russell

This paper (1) identifies the conditions most likely to result in decisions and actions favorable to habitat protection and enhancement; (2) addresses the actions necessary to create those conditions; and (3) describes one recently developed system that can be used to identify those actions most likely to result in favorable habitat. The information produced by the system is intended to be useful to environmental managers who are responsible for deciding how to remedy wildlife habitat losses.

Federal, state and local policies, set by politicians and administered by appointed officials, determine what resources will be developed and what resources will be sacrificed either temporarily or permanently. Those policies also determine whether and to what extent public and private financial resources are used to protect or enhance fish and wildlife habitat. Public policy amounts to the allocation of advantages and disadvantages (of one resource being utilized at the expense of others). Thus, protection of fish and wildlife habitat is ultimately a matter of politics.

An effective habitat protection process, then, must be compatible with the political process.

CONDITIONS THAT FAVOR EFFECTIVE HABITAT PROTECTION

There are numerous individuals who can decide (or influence those who do decide) whether or not actions are taken to protect habitat or replace lost or damaged habitat. Included are citizen advocates, persons locally responsible for wildlife in a state or federal wildlife agency, and higher level staff members within those agencies. Also involved are people in the agency or private interest promoting development, public policy makers and administrators responsible for the proposed development and policy makers who are not directly effected.

A decision can be made at any of the many levels of the process to provide limited or no habitat protection. Consequently, the likelihood that effective habitat protection will emerge from the political process is related to the degree to which the predicted results of environmental change can be clearly communicated to those persons who make or influence the decisions.

If habitat is to be protected, then several items of information would generally be helpful. For example: (1) what is wanted and by priority (how many of what kinds of animals are enough at the location in question); (2) what the extent of animal losses likely will be if the proposed development occurs; (3) what action could be taken to prevent or restore the expected animal losses; and (4) what would be the dollar costs of each of the preventative or remedial actions.

A second condition favorable to effective habitat protections is that the whole procedure be a positive experience for those who must fund the necessary action or

---

The Author: Dr. Kenneth R. Russell is leader, Colorado Cooperative Wildlife Research Unit, Colorado State University, Ft. Collins, and was Assistant Leader, Iowa Unit from 1969-1974. Principal professional emphasis has been on population analysis and design of systems to assist during the management decision process.

for those making the decisions that require payments to be made. The need must be rational—be it to comply with legal requirements necessary in order to secure material gains, to gain beneficial public relations, to avoid negative public relations, or to exercise moral responsibility. This rationale is strengthened if measurable benefits can be attributed to the required financial expenditures.

A third favorable condition is that the consumers or taxpayers collectively be willing to contribute to the protection or replacement of habitat. That condition can only be met if the need and prescribed remedial actions are communicated clearly by those who advocate the habitat protection.

The final favorable condition is that citizen environmental groups be reassured that the contemplated actions will indeed preserve environmental integrity.

HOW CONDITIONS THAT FAVOR HABITAT PROTECTION CAN BE CREATED

Several actions can be undertaken to bring about the favorable conditions described in the preceding section. The major ones are:

1. Creating an atmosphere of mutual assistance. Environmental agencies and organizations have a reputation in commercial and industrial circles for vigorous opposition to any change. That reputation impedes cooperation and might be diminished or even erased if habitat protection efforts were pursued as a means of maintaining net fish and wildlife yields *concurrent* with industrial, agricultural and cultural change.
2. Limiting data collection to specific information about the most important or representative species. Time and money resources otherwise required to gather information of marginal utility could then be directed toward actual habitat protection. Evaluation of only designated species also would reduce the data pool and the volume of the final report.
3. Translating the ecological and biological data generated into information units familiar to decisionmakers. This action would provide each decisionmaker with the option of addressing either the translated results or input data. This approach would also allow fully quantified impact assessments (e.g., how many fewer animals will there be in a particular animal population) and habitat replacement planning (e.g., how much land will have to be treated and how often at a cost of how many dollars, in order to replenish the reduced population).
4. Focusing habitat loss assessment and habitat replacement projections on the end result or outcome, rather than on the intermediate changes and relationships that are challenging enough to career biologists and ecologists without burdening time-pressed decisionmakers with them (unless required).
5. Predicting only the consequences of several sets of defined and possible conditions. This approach is less subject to error than predictions of exactly what conditions and associated consequences will exist at some point in the future. The latter predictions are precarious at best and vulnerable to any number of unforeseen events. By matching consequences with prescribed conditions only, more information and thus more bargaining latitude is provided to the decisionmakers who support habitat protection.

WILDMIS - ONE SYSTEM THAT CAN BE USED

One system developed recently that satisfies many of the information needs identified in the preceding discussion is called WILDMIS. The name is derived from Wildlife Management Information System.

BASIC PREMISES

The following premises were the fundamental considerations upon which WILDMIS was constructed.

When a land use disturbance is contemplated, answers to the question of what to replace or produce through reclamation, and what environmental conditions to create and in what amounts, are not self-evident. A solid stand of wheatgrass may provide ground cover and support grazing for livestock, for example, but has very limited value for most wildlife species. It can also be assumed that space and dollars available for mitigating actions will be limited; thus choices will have to be made regarding which wildlife resources will be enhanced and to what degree.

Decision processes can best be served if the information furnished to decisionmakers is focused primarily on the results produced by animal-specific actions as opposed to the ecological processes leading to the results. The probability of accurately predicting results, however, will increase proportionately by the increase in knowledge about the ecological processes involved. In the absence of complete and perfect ecological knowledge, estimated numbers of animals associated with given conditions can serve as an alternative basis for decisions about environmental actions.

Another premise of WILDMIS is that the fundamental actions and information required in the mitigation or management planning process does not vary with the nature of the disturbance. One needs the same types of information about environmental conditions whether the cause of the potential disturbance is oil shale development, coal mining, timber harvest, reservoir construction, dry land farming, or urbanization of rural areas.

Decisionmakers generally do not have the time, inclination or need to delve into the voluminous reasons a particular result is predicted. They do, however, need to know how one result or set of results compares with other sets of results when choosing between times, locations and kinds of disturbances. They also must know the cumulative results of numerous disturbances in a geographic region. These considerations comprise a need for a macroscopic approach to impact assessment and mitigation planning.

Species of plants and animals constitute the fundamental divisions of living components of ecosystems, and the end products of ecosystems are the individual animals that collectively form populations. Habitat, principally plants and the non-living environment in which the animals live, is the means to the end product—animals. At least animals are the end product insofar as public agencies responsible for their welfare are concerned. It follows then that the fundamental units upon which decisionmakers can most directly base decisions are the numbers of individual animals of each species involved in a decision. As those individual species are combined into groups of animal species represented indirectly by some index of habitat condition, the end products (individual animals) get lost in the process.

RECENT AND CURRENT APPLICATIONS

WILDMIS was initially created for and demonstrated in conjunction with oil shale development in Colorado and Utah.[1] Presently it is being applied and evaluated intensively in connection with phosphate development in southeastern Idaho by university graduate research assistants in cooperation with biologists in state and federal agencies. WILDMIS is also being used for coal mining impact assessment and mitigation planning and for ring-necked pheasant (*Phasianus colchicus*) enhancement management planning by state wildlife biologists in Colorado. The PATREC portion is being tested in Wyoming for dabbling and diving duck habitat classification. Accumulation of extensive experience with WILDMIS will take several years. One field evaluation of the habitat evaluation component of the system (PATREC) has been completed.[2]

OVERVIEW

WILDMIS translates ecological, biological, and management information bits into outputs (basically for one wildlife species at a time) that can be used simply and directly as the basis for land management decisions. Translation is accomplished through a set of independent but interrelated procedures that as a group have been labeled WILDMIS (Figure 1). Independent means that any one of the system components can be used without using any of the others. Information from the general case (accumulated knowledge, observations and experience that pertain to one animal species) is brought to bear on the specific case, i.e., a tract of land where predictions are needed relative to some contemplated change.

Outputs from the OBJSET and PATREC components can be generated manually. RANKER and MANALT require a computer and PATREC can be used through a computer. A detailed description of the components of WILDMIS can be found in Russell, et al.[1]

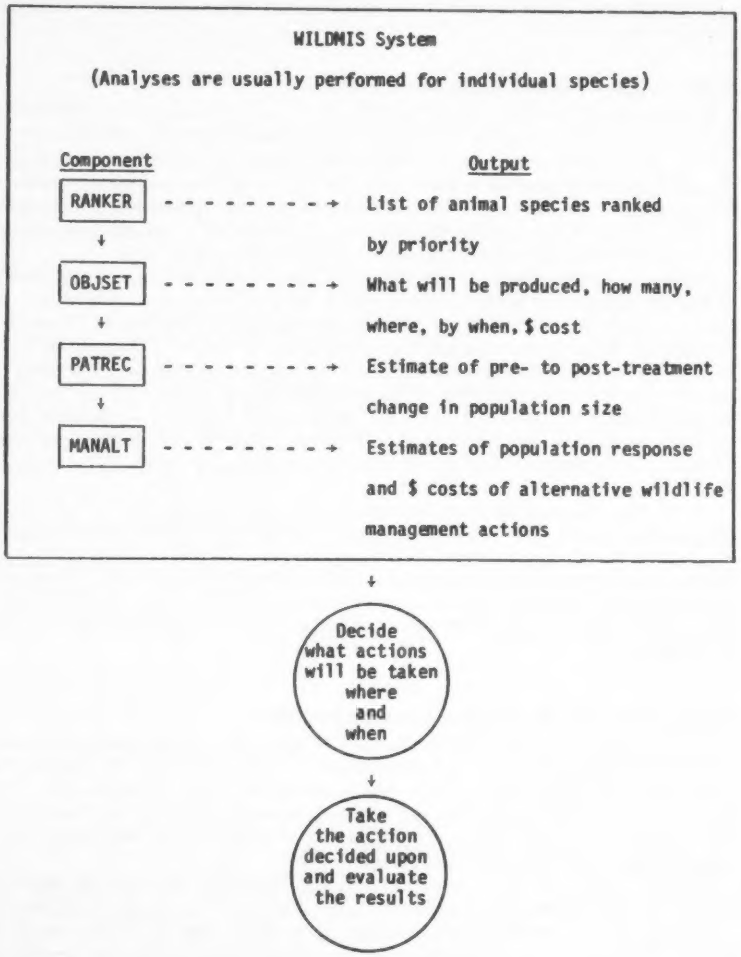

WILDMIS System
(Analyses are usually performed for individual species)
Component
Output
RANKER
List of animal species ranked by priority
OBJSET
What will be produced, how many, where, by when, $ cost
PATREC
Estimate of pre- to post-treatment change in population size
MANALT
Estimates of population response and $ costs of alternative wildlife management actions
Decide what actions will be taken where and when
Take the action decided upon and evaluate the results

Figure 1. WILDMIS System – components.

COMPONENTS OF WILDMIS

Ranking Wildlife Species by Priority - RANKER

Many criteria can have a bearing on which species become beneficiaries and which are omitted when decisions are made about investment of public or private dollars, space and time. These criteria can generally be sorted into four categories—ecological, public interest, cost to manage (cost of action taken to conserve, enhance or protect), and economic (production or suppression of income).

The RANKER system[3,4] can be used to rank any number of species according to integrated input related to the four criteria identified. The system does not address the one consideration that can override all of the above, political influence (both internal and external to an organization). RANKER has been used only in the oil shale application and is the least developed and least refined of the four WILDMIS components.

Setting Wildlife Production Objectives - OBJSET

If there are no formally stated wildlife production objectives for a particular management unit (i.e., number of animals in the population or harvest), an argument can be made that a reduction in yield is insignificant. On the other hand, if yield objectives formally adopted by the responsible agency do exist, and are accompanied by appropriate standards, then there is a base of reference against which a predicted habitat loss can be evaluated in absolute terms. The amount of the yield loss can also be related to the total current production of that management unit.

Further, a formal objective clearly communicates to all concerned exactly what is to be produced, how much is to be produced, where it is to be produced, by when, and what the probable cost will be. An example of a production objective is: "Produce a population of 120 deer on the Buckhorn Management Unit by 1 October 1987 at a total cost of no more than $650,000."* Accompanying standards should address (1) habitat (e.g., no more than 20% of the unit shall be comprised of saltbush-greasewood [Atriplex-Sarcobatus]), and (2) population (e.g., the 1 October herd composition shall be no fewer than 40 adult bucks: 100 adult does, and no fewer than 75 fawns: 100 adult does), and may include (3) recreation (e.g., the herd shall sustain a minimum annual harvest of 15 deer).

Given the existence of such conditions as public policy prior to a habitat disturbance, there is less likelihood of dispute over the extent of the mitigation action required to sustain that objective. The mitigation objective can be stated in identical format with only internal numbers modified to reflect the extent of the population loss that is to be replaced. This component facilitates the thinking required in order for a wildlife agency to decide exactly what it wants from a mitigation action, species by species.

Impact Assessment and Habitat Analysis - PATREC

The PATREC (derived from PATtern RECognition) habitat evaluation system provides two ways of measuring habitat values. The first is the probability (p 0.01 to 0.99) that a tract of interest has the potential to support a high density of a particular animal species. The second is an estimate of the population density that the tract has the potential to support. The density can also be expanded to provide an estimate of the potential population size on the whole tract.

The first order use of a tract analysis by PATREC is to estimate the potential population density (and total population size) under existing conditions (Table 1). The tract can then be reevaluated (using one or more new sets of conditions) to predict potential densities anticipated as a consequence of habitat changes (either

---

*Costs can be corrected after a cost-of-management analysis has been completed.

Table 1. Estimated potential population size of eight selected species of wildlife on one oil shale tract in Colorado[1]

	p(H)[1]	p(L)[2]	Estimated potential density on tract	Estimated potential population size on tract
Superior Tract				
Mule deer *(Odocoileus hemionus)*	0.54	0.46	35/mi² (14/km²)	364
Elk *(Cervus canadensis)*	---	---		
Mountain lion *(Felis concolor)*	0.97	0.03	9.7/100mi² (4/100km²)	1
Golden eagle *(Aquila chrysaetos)*	0.77	0.23	7.9/100mi²	0.8 (3/100km²)
Peregrine falcon *(Falco peregrinus)*	0.22	0.78	---	
Sage grouse *(Centrocercus urophasianus)*	0.35	0.65	18/mi² (7/km²)	187
Mountain bluebird *(Sialia currucoides)*	0.87	0.13	53/mi² (20/km²)	551
Mallard *(Anas platyrhynchos)*	0.07	0.93	6/100ac (15/100ha)	2

[1] **Read: The probability is $\underset{p(H)}{\underline{\hspace{2cm}}}$ that this tract supports, or under the set of environmental conditions described has the potential to support, a high $\underset{\text{species}}{\underline{\hspace{3cm}}}$ population density.**

[2] **Read: The probability is $\underset{p(L)}{\underline{\hspace{2cm}}}$ that this tract supports, or under the set of environmental conditions described has the potential to support, a low $\underset{\text{species}}{\underline{\hspace{2cm}}}$ population density.**

favorable or unfavorable). The difference between the two sets of population estimates would provide a measure of the impact of a negative change in habitat, or a measure of the increased yield resulting from a favorable change in habitat (e.g., through an enhancement management action). The change can be expressed as a decrease or an increase in the number of animals on the tract. This difference can then serve as the basis for formulation of a mitigation or enhancement production objective statement. The above estimates should be viewed as relative rather than absolute because of the many non-habitat conditions that also influence population size.

An additional use is to simulate one or more changes in habitat conditions to reveal what environmental conditions would have to be changed and by approximately how much in order to attain some designated yield objective.

By evaluating an array of tracts it can readily be shown which are most and which are least valuable as habitat for one or more species (Table 2). Rankings of this type can provide input to decisions involving the sequence in which tracts will be disturbed, and which tracts are preferred candidates for disturbance or protection. Such rankings can also be used to project the cumulative impacts of a number of separate disturbances on a particular species.

Finally, PATREC can be used for habitat classification or inventory. Applied over a large area (large being relative to the life cycle requirements of the animal for which the habitat is being classified), the probability values (0.01-0.99) for the potential population density to be high can be divided into increments (e.g., of 10) and plotted on a map to represent areas of different habitat quality.

PATREC can be applied quickly and inexpensively and can provide predictions as accurate as current knowledge permits or as circumstances warrant. The logic of the

Table 2. Ranking of 14 oil shale tracts in Colorado and Utah by mountain bluebird nesting habitat quality according to PATREC results, September, 1979.[1]

Tract	p(H)	p(L)	Estimated potential density on tract (bluebirds/mi^2)	Estimated potential population size on tract*
1. Colony	0.97	0.03	58 (22/km^2)	372
2. Paraho	0.96	0.04	58 (22/km^2)	111
3. C-5	0.93	0.07	56 (22/km^2)	447
4. C-2	0.93	0.07	56 (22/km^2)	442
5. Superior	0.87	0.13	53 (20/km^2)	551
6. C-a	0.86	0.14	52 (20/km^2)	411
7. C-b	0.86	0.14	52 (20/km^2)	413
8. Occidental	0.85	0.15	52 (20/km^2)	325
9. Union	0.70	0.30	44 (17/km^2)	1,421
10. U-9a	0.93	0.07	14 (5/km^2)	112
11. Geokinetics	0.60	0.40	11 (4/km^2)	11
12. Tosco (except NE)	0.13	0.87	6 (2/km^2)	104
13. Ua/Ub	0.13	0.87	6 (2/km^2)	96
14. U-8	0.13	0.87	6 (2/km^2)	48

***Should be interpreted as follows: The estimated potential population size according to the acreage figures, PATREC models and environmental measurement data used. Each of those conditions constitutes a possible source of error in the resulting estimates.**

method can be readily understood by persons who are not trained as life scientists. Moreover, application to a given tract can be entirely quantified and objective.

PATREC contains just two parts. One is a questionnaire usually consisting of about 10 questions (Figure 2). Each question pertains to a particular environmental condition—whether it occurs on the tract, and within what range of amounts. The questions are based on the environmental conditions that exist where the animal occurs in very high densities and where it occurs in very low densities. The ranges of

PATREC Model for Northwest Colorado/Northeast Utah

Sage Grouse
Habitat Evaluation Model

Population Density Standards: High = 50/sq. mi.; Low = 1/sq. mi.
Prior Probabilities: High = .30; Low = .70

1. What is the size of the continuous sagebrush community?

		High	Low
	a. <1000 acres	.15	.25
	b. 1000-5000 acres	.35	.45
*	c. >5000 acres	.50	.30
	d. No data		

2. What percent of the sagebrush community is interspersed with meadows, riparian zones or irrigated farm lands?

		High	Low
	a. <5%	.20	.25
	b. 5-15%	.25	.25
*	c. 15-30%	.30	.20
	d. >30%	.25	.30
	e. No data		

3. What is the average distance to open, permanent water?

		High	Low
*	a. <2 miles	.50	.35
	b. 2-4 miles	.30	.35
	c. >4 miles	.20	.30
	d. No data		

4. What percent of the sagebrush community has a slope less than 10 percent?

		High	Low
	a. <30%	.15	.30
	b. 30-60%	.35	.35
*	c. >60%	.50	.35
	d. No data		

5. What is the distance to a known strutting ground?

		High	Low
*	a. <2 miles	.50	.15
	b. 2-6 miles	.35	.40
	c. >6 miles	.15	.45
	d. No data		

6. What is the percent canopy cover within the sagebrush community?

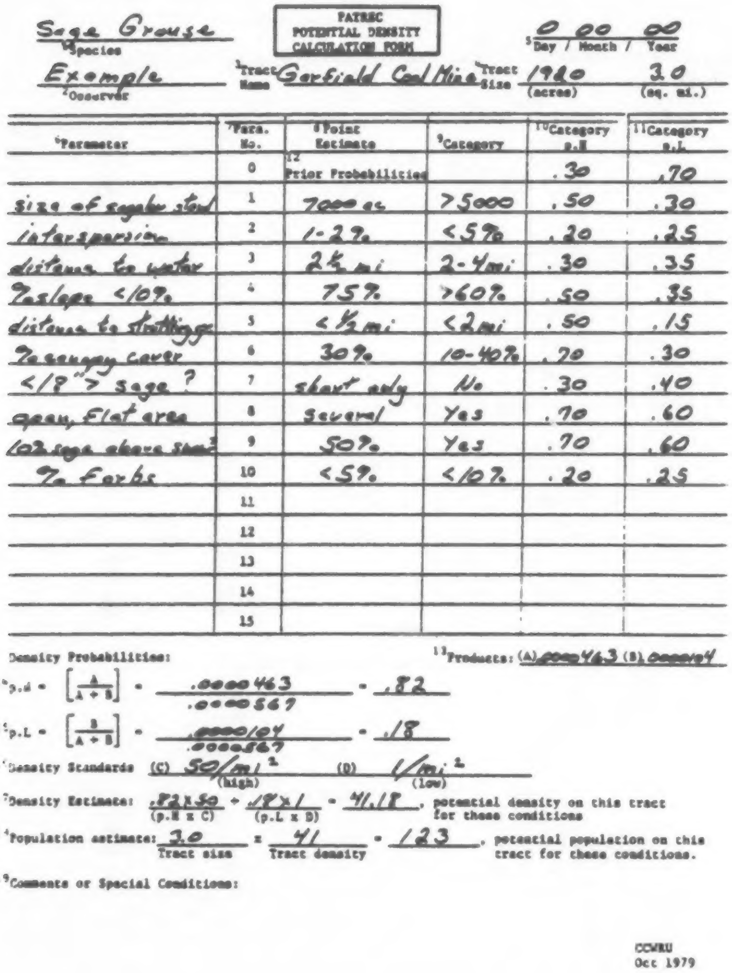
		High	Low
	a. <10%	.10	.30
*	b. 10-40%	.70	.30
	c. >40%	.20	.40
	d. No data		

2 Oct 79 CCWRU

Figure 2. PATREC Model for Northwest Colorado/Northeast Utah – Sage Grouse habitat evaluation model.

amounts are accompanied by the frequency with which each range is found in association with the same very high and very low population densities.

The second part of the system is a one-page density calculation form (Figure 3). Each response to the questionnaire is recorded on the form when a tract is being evaluated. All calculations are then made, a process that takes about three minutes with a hand calculator. The concepts and mathematical theory upon which the PATREC system is based are reported in Williams et al.[5] and are derived from mathematical procedures used for a number of years for medical and business decisionmaking.



PATREC
POTENTIAL DENSITY
CALCULATION FORM

4 Species: Sage Grouse
5 Day / Month / Year: 0 00 00
2 Observer: Example
3 Tract Name: Garfield Coal Mine
6 Tract Size: 1920 (acres) 3.0 (sq. mi.)

6 Parameter	7 Para. No.	8 Point Estimate	9 Category	10 Category p.H	11 Category p.L
	0	12 Prior Probabilities		.30	.70
size of sagebr stand	1	7000 ac	>5000	.50	.30
interspersion	2	1-2%	<5%	.20	.25
distance to water	3	2½ mi	2-4 mi	.30	.35
% slope <10%	4	75%	>60%	.50	.35
distance to strutting gr	5	<½ mi	<2 mi	.50	.15
% canopy cover	6	30%	10-40%	.70	.30
<18" > sage ?	7	short only	No	.30	.40
open, flat area	8	several	Yes	.70	.60
10% sage above snow?	9	50%	Yes	.70	.60
% forbs	10	<5%	<10%	.20	.25
	11				
	12				
	13				
	14				
	15				

Density Probabilities:

13 Products: (A) .0000463 (B) .0000104

14 $p.H = \left[\frac{A}{A+B}\right] = \frac{.0000463}{.0000567} = .82$

15 $p.L = \left[\frac{B}{A+B}\right] = \frac{.0000104}{.0000567} = .18$

16 Density Standards (C) 50/mi² (high) (D) 1/mi² (low)

17 Density Estimate: .82 x 50 (p.H x C) + .18 x 1 (p.L x D) = 41.18, potential density on this tract for these conditions

18 Population estimate: 3.0 (Tract size) x 41 (Tract density) = 123, potential population on this tract for these conditions.

19 Comments or Special Conditions:

CCWRU
Oct 1979

Figure 3. PATREC Potential Density Calculation Form — Sage Grouse.

One of the principal advantages of PATREC in an impact assessment application is that it limits the wildlife baseline data collection effort to only those species of interest. The accumulation of large volumes of data of uncertain usefulness can thus be avoided.

In the process of constructing a PATREC questionnaire (also called a PATREC model), it will probably become evident that even the most experienced biologist does not fully know what environmental conditions present in what ranges of amounts are associated with the highest and lowest population densities for the species in question. This points to a potential need for a specific habitat requirements research effort.

No serious attempt has been made to use PATREC for fisheries habitat analyses, though it does appear that the concept could be applied there as well. Also there has been no rigorous effort made to incorporate data on environmental contaminant levels into a PATREC model. However, there is nothing inherent in the procedure that would preclude this, given that, applicable data exist for high and low population conditions.

Cost-of-Management Analysis - MANALT

Estimating the full array of costs required to complete a wildlife management action is a task that probably no wildlife manager relishes. Estimating all related costs for all possible management actions applicable to a particular animal species, and then for a number of species, is an appalling prospect to nearly all managers. Consequently, management actions may often be selected with less than critical considerations of (a) all available options; (b) the likely increase in production (if any) stemming from the action; or (c) the benefit; cost ratio of each option.

The MANALT (MANagement ALTernatives) system was created to help offset those deficiencies in the management planning process. Specifically, it is predicated on the assumption that managers would make use of output information if it were more conveniently available.

MANALT was created as a tool for estimating the costs of favorable habitat changes. It is a basic wildlife management and budget plan stored in a computer, readily available through an interactive terminal with copies of output immediately available at the press of a button. Any value stored in the program that is incorporated into any calculation can be changed to one preferred by the person using the program at the time.

The principal output of the MANALT program is a cost effectiveness summary (Figure 4). It displays the total project cost, total increase in wildlife production (either population or harvest) over the entire benefit life of the management action(s) being evaluated, the cost per unit produced (added to the population or harvest) and a cost efficiency index.

The cost efficiency index is probably the only feature unique to MANALT. The purpose of the index is to allow the manager to rank two or more management action options under consideration. The index provides a measure of the cost per unit produced, in combination with the probability (0.01-1.0) that the yield prescribed will actually be attained. The probability value is subjective, but requires the manager to think about whether he or she is certain (p = 1.0) to get the results as scheduled, or whether he or she might get something less for the dollars invested. Hazards to total success could include heavy rains or sustained drought following treatment, fire, very high winter mortality, unexpected changes in harvest regulations, or other unforeseen events. The index is a simple but quantified allowance for Murphy's law (whatever can go wrong, will) and provides a safeguard against overly optimistic yields expected from mitigating actions. As yield rate estimates decline, probability of success values would normally be raised for a specific management action. The higher the cost efficiency index value, the higher the cost effectiveness of the management action.

```
Strategy — WTRRNGFERT/MMOK

1.  DEV + O/M Costs = $470,793.40

2.  Discounted DEV + O/M Costs = $409,039.82

3.  Total Goal Units = 3,511

4.  Cost/Unit (Item 1/Item 3) + $134.08

5.  Discounted Cost/Unit (Item 2/Item 3) = $116.50

6.  Probability of Success = 80%

7.  Efficiency Index (Item 6/Item 4) = 5,966

8.  Efficiency Index (Discounted) (Item 6/Item 5) + 6,867

    Do You Wish to Change the Probability of Success?
    ? yes
```

Figure 4. Cost Effectiveness Summary - Strategy - WTRRNGFERT/MMOK (winter range fertilization applied to mountain mahogany - oak scrub (Cercocarpus-Quercus). Dev + O/M means development plus operation and maintenance costs.

An intermediate output display of planning value is the cost/strategy implementation profile (Figure 5). It shows the expenditures required each year over the life of the project.

As with PATREC questionnaire construction, MANALT data bank entry efforts will identify specific research needs, particularly with regard to management effectiveness evaluations.

WILDMIS LIMITATIONS

One condition that may limit the use of WILDMIS as a routine operational tool in habitat protection and management consists of the thinking habits of people, especially the habit of being vague and non-committal. WILDMIS requires specific thinking with respect to setting priorities and objectives, defining habitat requirements and predicting the production increase that results from a management action. It also requires a commitment by the user to make a rational guess in lieu of perfect and complete data. My experience with managers and biologists indicates that having to be specific and committal under imperfect conditions often makes them uncomfortable. However, I have found also that the discomfort can eventually be displaced by rising confidence after appropriate questions have been asked and participants begin to recognize that they (a) really knew more about the subject than they realized they did, and (b) the consequences of providing specific estimates in lieu of perfect knowledge, even if somewhat in error, will not be calamitous. Often, just providing order and structure to the analytical process and documenting those conclusions, results in habitat protection advocates being in a more defensible position.

Another limitation to the use of WILDMIS is a bona fide lack of applicable data. That condition may exist regardless of what approach to decisionmaking is used. WILDMIS simply pinpoints what data are missing but necessary to make informed

```
              Detailed Cost/Strategy Implementation Profile

Strategy - ESTWINTCVR/ANY
 Cost for 2.00 Units Starting in Year 1

            Year   1                                                Totals
DEV             8190                                                  8190
DIS DEV         8190                                                  8190

            Year   1    Year   2    Year  11    Year  21    Year  31
O/M                0         184         630         630         630
DIS O/M            0         180         565         511         463

            Year  41                                                Totals
O/M              630                                                  2704
DIS O/M          419                                                  2138

Press Return to Continue
?
```

Figure 5. Detailed Cost/Strategy Implementation Profile - Strategy - ESTWINTCVR/ANY (establish winter cover in any habitat type).

decisions. This limitation can be substantially reduced, given sufficient time and a commitment of financial and personnel resources.

A third limitation is the lack of historical proof that WILDMIS or any of its components really "work." Logic and risk will have to be substituted for demonstrable results for several years. The alternative is to continue with old ways, which, judging from habitat and wildlife population loss rates, have not themselves been shown to work particularly well.

Mention of the words "systems," "models" or "computers" in connection with wildlife management sometimes creates a negative attitude and a feeling among some people that sophisticated technologies will or might displace personal experience, knowledge and judgment. On the contrary, the most valuable contributions to date of the input information that drives WILDMIS have come from research and management biologists with many years of experience. This kind of logical, structured information processing can actually make the individually-held knowledge of wildlife research and management professionals more useful in the decisionmaking process.

Finally, to use a new method requires learning. There is enough written information available so that anyone having basic biological training could become a self-taught and a proficient user of the whole WILDMIS system. There is nothing technically rigorous or mysterious within it.

CONCLUSIONS

Ten years ago there was no comprehensive and systematic approach to setting wildlife production objectives, analyzing habitat and choosing among alternative wildlife management actions. The research that resulted in WILDMIS provides such a device. Perhaps the most valuable potential of WILDMIS lies in improved communication between biologists and the public through the translation of scientific detail into numbers of animals and dollars, measurements more readily understood by persons who make policy and action decisions.

By making the analysis of action options convenient, specific, and quantitative, WILDMIS can increase a manager's capability to analyze consequences of negative and positive habitat changes, identify favorable options, and estimate the amount and cost of corrective action needed. As a result, future on-the-ground wildlife management efforts should be more effective.

The habitat assessment component, PATREC, appears to satisfy most or all of the expectations of wildlife field personnel for habitat assessment methodologies.[6] WILDMIS, on the whole, appears to meet at least some of the goals and objectives for research needs in wildlife indentified by Sanderson et al.[7] Experience with WILDMIS to this point has revealed three additional needs that, if met, would further increase potential management effectiveness. The first is a need for wildlife management cost and benefit analysts—those persons who have the skills to identify habitat management inputs, measure all of the outputs and evaluate them together. Another is the need for a permanent, broad spectrum training institute that can provide practicing biologists effective instruction and follow-up consultation on newly developed ways of doing business (especially computer-based procedures). Sources of valuable new technologies are not limited to any particular type of agency,institution or organizational unit. But, there is presently no formal provision for consolidating and disseminating those advancements on a large or dependable scale. Scientific literature is only partially adequate. Finally, a central facility where newly created data banks could be deposited and withdrawn could save agencies a substantial amount of time and money by reducing duplication of effort.

ACKNOWLEDGEMENTS

W. K. Seitz, S. R. Amend, D. R. Dietz, R. W. Streeter and G. L. Williams all have contributed to the content of this paper through technical input, review of the manuscript and fostering the basic ideas presented. B. A. Klein typed the manuscript. To each of these persons I extend my thanks.

REFERENCES

1. Russell, K.R., G.L. Williams, B.A. Hughes, and D.S. Walsworth. 1980. WILDMIS—A wildlife mitigation and management planning system—demonstrated on oil shale development. Colorado Coop. Wildl. Res. Unit, Colorado State Univ. Ft. Collins, Colo. 152 pp.
2. Kling, C.L. 1980. Pattern recognition for habitat evaluation. M.S. Thesis, Colorado State Univ. Ft. Collins, Colo. 240 pp.
3. Hughes, B.A. 1978. Factors affecting wildlife mitigation choices in the oil shale region. M.S. Thesis, Colorado State Univ. Ft. Collins, Colo. 199 pp.
4. Williams, G.L., B.A. Hughes and K.R. Russell. 1980. RANKER—A computer program for ranking priorities among wildlife species. Colorado Coop. Wildl. Res. Unit, Colorado State Univ. Ft. Collins, Colo. 28 pp.
5. Williams, G.L., K.R. Russell, and W.K. Seitz. 1977. Pattern recognition as a tool in the ecological analysis of habitat. pp. 521-531 *In* Classification, inventory, and analysis of fish and wildlife habitat. Proc. of a national symposium, Phoenix. FWS/OBS-78/76. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.
6. Amend, S.R. 1980. An interim report on habitat assessment methodologies as viewed by the field. Prepared for the Colorado Coop. Wildl. Res. Unit, Colorado State Univ., and Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, USDI. Fort Collins, Colo. 15 pp.
7. Sanderson, G.C., E.D. Ables, R.D. Sparrowe, J.R. Grieb, L.D. Harris, and A.N. Moen. 1979. Research needs in wildlife. Trans. Forty fourth N. Amer. Wildl. and Nat. Resour. Conf. Wildlife Management Institute. Washington, D.C.

WILDLIFE RECLAMATION OF MINED LANDS

W. D. Klimstra

Surface mining and all of its impacts came under intense scrutiny during the past decade. While the nation's rising environmental consciousness was being translated into new legislation, the energy crisis steadily escalated. America's vast coal resources were seen as a replacement for our diminishing supplies of oil. The clash between energy and environmental concerns was reflected in the long and heated debate which led to the passage of Public Law 95-87 "Surface Mining Control and Reclamation Act of 1977."

The debate was sharpened by the surge of surface coal mining development in the west, an area of fragile soils, limited water and sparse population. The sudden and massive strip mining of formerly undisturbed open range land aroused opposition among some local residents. Many were concerned over the fact that coal—the cause of the disruption—was being shipped away for use elsewhere. Indeed, it was a new experience to accept coal as a crucial resource. The growing concerns were not confined to the west. In the midwest and the east there was increasing anxiety over the effects of surface mining on prime farmland and the hills and valleys of Appalachia.

One result of these concerns was a rapidly emerging need for an interest in baseline data (which fortunately included the native fauna and flora). State and federal agencies became involved in the early stages of resource development. They evolved techniques for rapidly gathering data for extensive areas because ecosystems rather than localized settings were affected. During the past decade, numerous handbooks, guidelines for studies, and systems and model designs for decisionmaking appeared. The utility of many, if not most, of these has not yet been fully tested and established.

During the decade of the seventies there were workshops, seminars, and conferences of local, regional, national and international scope which directly and indirectly addressed the impact of surface mining and mined land reclamation on fauna and their habitats. Typical were such events as: "Mitigation Symposium: a national workshop on mitigating losses of fish and wildlife habitats," "Surface Mining and Fish/Wildlife Needs in the Eastern United States: Proceedings of a Symposium," "Symposium on Restoration and Recovery of Damaged Ecosystems," "Research and Applied Technology Symposium on Mined Land Reclamation," "International Conference for Energy and the Ecosystems," "Economics, Ecology and Planning of Coal Resource Development," "Symposium on Mining and Ecology in the Arid Environment," "Proceedings of the Third Annual Meeting of the Canadian Land Reclamation Association," and "Proceedings of the Fort Union Coal Field Symposium."

Papers reflecting various points of view, philosophies, and wildlife-related problems were also published. Early in the decade the literature emphasized negative

---

The Author: Dr. Klimstra is Professor of Zoology and Director, Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale. He participates on State and National advisory boards concerning natural resource planning and management. He has held several posts while at the University including Acting Director, Coal Research Center and has pioneered innovative applied research for restoration of fish and wildlife to coal surface-mined lands in Illinois and the midwest.

aspects, especially problem conditions which prevailed during and following mining. Gradually the emphasis changed—focusing more on how wildlife might benefit by reclamation efforts during preplanning and mitigation processes.

The recognition of both the negative and positive impacts of surface mining on wildlife generated a sudden increase in funding for staff research. The goal was better understanding. Prior to the 1960s (even in the early 1970s) only a few were looking with interest at surface mined lands as wildlife habitats. The growing interest and effort largely developed because it was noted that viable and valuable habitats were or could be created on surface mined lands (Figures 1 and 2). This was most appreciated when rapidly evolving intensive land use, especially monoculture, essentially "dehabitated" once-productive wildlife support systems. Resource scientists recognized that the recovery of land via normal processes (enhanced by reclamation) yielded a break in the monotony of monoculture. They saw an opportunity for wildlife enhancement, even in the face of state laws which emphasized "as it was before" reclamation. The interest and motivation grew and, in the face of great odds, influenced the final version of PL 95-87. The law incorporated significant language on regulation and reclamation which ensured at least limited consideration of wildlife and habitat values at various stages from planning through permitting to mining and reclamation.

Over the years, research and other organized efforts reflected an increasing awareness of problems and opportunities confronting wildlife, its habitats, and its management. Early studies largely addressed fauna and population levels, how they related to non-impacted lands, processes of succession, and man's use of these sites for harvest of game species. Later there was more emphasis on the possible reclamation and development of such areas for greater public use (including outdoor recreation). Research was motivated to more clearly delineate why and how reclamation might accommodate needs of wildlife. The research also stressed that mining resulted in changes and losses in our fauna and it was therefore a responsibility of reclamation to replace habitat for native fauna. To reflect what was happening,

Figure 1. A struck-off spoilbank, seeded to *Sericea lespedeza* and orchard grass to establish diversity and openings for wildlife in an area mined in 1940.

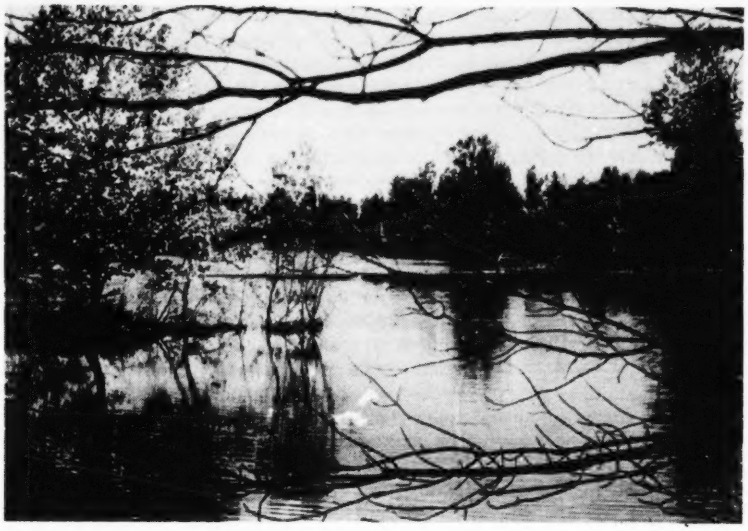


Figure 2. A beaver lodge in a lake resulting from surface mining which was reclaimed through natural revegetation.

studies of the changes emphasized the "before" and "after" and implementation of mitigation concepts previously conceived by the U.S. Army Corps of Engineers. Further, efforts were directed towards identifying, testing, and establishing plant species, thus meeting reclamation needs emphasized in laws, rules and regulations.

SELECTED LITERATURE

As of July 1, 1977, the mineral industry had disturbed 5.7 million acres (2.3 million ha) in the United States.[1] In order to meet future energy demands, much more land will be disturbed by mining. Wildlife habitat has been restored and introduced on abandoned and newly-mined lands in all parts of the United States via natural revegetation and/or highly developed reclamation techniques.

This paper presents an overview of selected activities of the past 10 years (1970-1980) which reflect efforts involving both the evaluation of surface mining effects on our fauna and mined land reclamation for wildlife in the United States. Environmental conditions (precipitation and temperature) and man's needs and desires (food, recreation, timber, industry, and housing) have defined the quantity and quality of the wildlife habitat resulting from reclamation. While livestock grazing has been the single most important factor affecting wildlife production in the west,[2] intensive agriculture and timber harvest have been impacting factors in the Midwest and Appalachian regions.[3,4,5]

Tyus and Lockhart[6] suggested reasons for optimism about the possibilities for wildlife enhancement on mined land: (1) cooperation of mining companies; (2) a lead time of 10 or more years from early planning until actual operations begin, thus providing adequate time to assess important wildlife needs and to develop management options; (3) wildlife reclamation measures are usually lower than those costs associated with other types of reclamation; and (4) mining and reclamation can be carried on at the same time for extended periods. With changes in techniques, reclamation practices can be adjusted accordingly.

Although the primary objective of mitigation measures is revegetation, site-specific evaluations and procedures are needed to obtain maximum results. For example, a uranium mine will have a smaller impact on vegetation and soil removal than a surface coal mine or an open pit shale operation. The chance of contamination of runoff or water supplies by toxic substances will normally be greater for oil shale, uranium, and eastern coal mines than for western coal operations.[7]

Streeter, et al.[8] identified several site-specific factors requiring consideration when evaluating the effects of mining on wildlife resources:

"1. species of fish and wildlife present and their interrelationships;
2. seasonal use of the area by wildlife (e.g., winter, transitional or summer range);
3. unique wildlife uses of the area, such as reproduction, epigamic display, migration, or wintering;
4. availability and condition of adjacent habitats;
5. physical size and expected duration of the mining operation;
6. relative importance to wildlife of the affected habitat; and
7. time frame and extent of other related activities in the vicinity."

All coal, uranium, and phosphate surface mines in the 11 western contiguous states (plus North Dakota and South Dakota) that were larger than 10 acres and in operation before 1976 have been evaluated.[9] Each mine was categorized as to geographic location, operator, surface and subsurface ownership, summary of mining plan and methods, dates of operation, area affected by mining activities, reclamation history where applicable, and current land use and vegetation conditions.

A new technique for projecting environmental impacts has been developed in a study by the U.S. Environmental Protection Agency (EPA), Environmental Research Lab in Corvallis, Oregon.[10] It involves the application of mathematical equations to planning and decisionmaking. A second method, called "Habitat Evaluation Procedures," is under development by the U.S. Fish and Wildlife Service (FWS).[11] It consists of: (1) applying index values to existing habitat conditions; (2) identifying differences between index values of existing conditions and expected values after development; and (3) establishing, in habitat value units gained or lost, beneficial versus adverse impacts realized due to development.

Another study, applied to the Yampa River basin in Northwest Colorado, evaluated a new approach to land and water project impact analysis. A computerized Geographic Information System (GIS) permitted management and analysis of mapped information that was impractical by manual means. Mapped wildlife data were composited to identify habitat values of land units. Proposed locations of coal and water developments then overlaid on composited wildlife maps to identify potential conflicts. A method was created which yielded quantification and comparison of relative impacts on wildlife for development schemes.

Another effort[12] yielded results of an extensive survey of over 400 existing data bases for Montana and Wyoming. This project, sponsored by the FWS Western Energy and Land Use Team (WELUT), was designed to promote more effective consideration of fish and wildlife resources in state and federal decisions involving western resources. *A Systems Approach to Ecological Baseline Studies*,[13] developed in anticipation of expanding western resource development, provides guidelines for ecological baseline studies for energy conversion projects.

A major program involving the FWS is the Federal Coal Management (leasing) Program, suspended in the early 1970s but recently renewed. The Secretary of the United States Department of Interior (USDI) has mandated a coal leasing program in which the Fish and Wildlife Service exercises a key role in reviewing leasing actions, providing information, participating in environmental assessments, preparing impact statements, identifying lands unsuitable for coal mining/leasing, and prioritizing mineral-bearing lands.

The mechanisms for participation and input are detailed in a Memorandum of Understanding on coal between the Fish and Wildlife Service and the Bureau of

Land Management (effective September 26, 1978) and the regulations for the Federal Coal Management Program.[14] The FWS recently developed[15] a set of Rapid Assessment Methods (RAM) that could significantly assist FWS and BLM field personnel in making decisions and solving problems related to selection of lands to mine, ranking sites, arranging leases, and land reclamation. RAM provides analytical tools, including land cover maps, existing resource data, and several ecological analysis and decision-oriented models.

The greatest disturbance of western lands has occurred within the grassland ecosystems of the Northern Great Plains and the Sagebrush Steppe vegetation unit of the Intermountain Regions. Limited precipitation and poor spoil characteristics result in slow natural revegetation. Therefore, reclamation of mined land must be performed under strict regulations to ensure maximal results.[9,16,17]

Dittberner[7] reported extensive literature on the propagation of western native plants. Evans, et al.[9] stated that several research studies conducted at large coal mines in the Four Corners area have revealed that soil moisture conditions can be enhanced by mulches and irrigation. Although reclamation programs at inventoried phosphate mines were generally designed to return mined land to a rangeland ecosystem with grazing as the land-use objective, several mines included provisions for wildlife migration routes and wildlife use. Big game species such as deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and moose (*Alces alces*) have been reported at all inventoried mining sites in Idaho.

A state game management area resulted from local reclamation efforts in North Dakota.[9] Trees, shrubs, and herbaceous species were planted by community groups. A large variety of wildlife now utilize the area. In some portions of North Dakota, sand and gravel pits contribute the only permanent wildlife habitat for extensive areas.[18] Because prairie dogs (*Cynomys ludovicianus* and *gunnisoni*) constitute 50% of the diet of golden eagles (*Aquila chrysaetos*), past destruction of large prairie dog towns must be compensated for. Eagle nest relocation seems successful (Denver Wildl. Res. Center, 1976b; Tyus and Lockhart, 1979). The application of the mandate for "lands unsuitable" should mediate such problems in the future.

Surveys were conducted from 1975 through 1978 in Montana to gather information on the effects of surface mining on pronghorn antelope (*Antilocapra americana*) habitat.[19] Identified animals left ranges when mining increased, but returned the following winter.

During the seventies, there have been extensive efforts to reclaim Midwest mined land for wildlife. These efforts have emphasized selected plant species, alleviation of acid spoil and water, re-introduction of native species, and compilation of baseline data.[4,9,20,21,22] While Grandt[24] found that row crop yields on newly mined and graded lands were lower than county-wide levels, Deknatal[3] emphasized that non-agricultural uses were in competition with crop production.

While the need for agriculture should not be ignored, a determined effort should continuously be made to include wildlife habitat in reclamation land-use plans. Several studies have demonstrated that provisions for wildlife habitat can be incorporated into a wide variety of planned land uses.[4,25,26] Wildlife habitat can be considered not only a secondary reclamation alternative; it can also be a primary objective (where prime agricultural lands do not have priority) because of the relatively low cost compared to other uses. Indeed, naturally revegetated land often yields adequate to excellent wildlife habitat, thereby drastically reducing reclamation costs. In other situations, only minor effort is required to facilitate vegetation establishment and/or manipulation on spoilbanks. On naturally revegetated mined land in southern Indiana, 45 percent of the plant species were found to be useful as fruit, forage, or cover for wildlife.[27]

The response of wildlife to differing reclamation strategies has been documented. Konik[28] characterized quality water and associated fauna and flora. He concluded that wetlands of surface-mined lands were significant contributors in compensating for the loss of natural wetlands.

Comparison of habitats before and after mining[29] reflected greater mammal and bird diversity on unmined lands in contrast to larger numbers of a few species on reclaimed lands. In addition, ungraded, natural-vegetated mined lands yielded greater diversity than graded revegetated (grass) acreages. The mined area wetlands provided important habitats for shorebirds, waterfowl, and several aquatic-related mammals. The extensive grass-covered reclaimed areas had significant numbers of birds of prey because of the increased populations of *Microtus*. Such data clearly identify the significant contributions of surface-mined lands to wildlife and their habitats which are in short supply, especially in areas impacted by monoagricultural practices.

An example of the emphasis on species in wildlife management has been demonstrated at the White Pine Copper Mine in Michigan. Borrow pits have created habitat for nesting populations of surface-feeding ducks. Grading and planting have created forage areas which have attracted thousands of geese during fall migration. Basins are utilized by white-tailed deer (*Odocoileus virginianus*) and are potential habitat for sharptailed grouse (*Pediocetes phasianellus*). Sandusky[30] has recorded very positive responses by waterfowl to nesting habitats provided by land and water reclamation in southern Illinois.

The Cooperative Wildlife Research Laboratory, Southern Illinois University, has used vegetation (especially *Phragmites*) to control levee erosion in slurry areas and created wildlife habitat as a by-product.[31] Data suggesting the importance of natural revegetation of gob and slurry sites as wildlife habitat are also being collected. Also, the Cooperative Wildlife Research Laboratory (unpubl. data) has documented the successful establishment of a breeding population of Giant Canada Geese (*Branta canadensis maxima*) on surface-mined areas in west-central Illinois (Figure 3). Waters with island-type habitats were especially productive. Nesting success of this population exceeded that generally recorded for any race of Canada geese. Other studies by the Laboratory (unpubl. data, Cooperative Wildlife Research Laboratory)

Figure 3. A member of the giant Canadian goose population which was reintroduced to the wetlands of Fulton County, Illinois, through surface mining reclamation in an intensively farmed prime agricultural area.

show a potential for re-introducing the prairie chicken (*Tympanuchus cupido*) on extensive contiguous acreages (10,000-20,000) of surface-mined lands revegetated with forage crops. Reclamation practices also contribute importantly to habitat needs of muskrats (*Ondatra zibethicus*).

Argonne National Laboratory has established an extensive list of mammals, birds, amphibians, and reptiles occupying a reclaimed coal refuse site.[22] Available data indicate that wildlife will repopulate reclaimed mined land, even problem sites, where harsh environments existed.

While reclaimed wildlife habitat in the Midwest and West is uniquely associated with monoculture, the contour-mined Appalachian area exhibits a "fractured" forest habitat. This intrusion can be viewed in at least two ways. One is the newly created habitats, largely strips of grassland, have provided for new and increased numbers of given species, birds in particular.[8,31,33,34,35,36,37,38] Whitmore and Hall[37] noted that such areas, produced by surface mine reclamation, represent an important (if perhaps temporary) addition to the habitat of the region since 74 percent of West Virginia is forested. The interruptions of forest habitat provides miles of linear edge which creates opportunities for maximal diversity of animal and plant species.[39] On the other hand, a decline in forest species may occur because of reduced contact with adjacent forest and an infringement on the natural woodland community. Yahner and Howell[38] found this to be true in their study of a mined area in eastern Tennessee.

The Appalachian region has been involved in reclamation work reflecting advances in technology. An exhaustive amount of research has been done on wildlife utilization of mined land which has been reclaimed or undergone natural revegetation. Tolin[40] investigated bioaccumulation of heavy metals in wildlife-inhabited strip-mined areas in eastern Ohio. He found no significant trends reflecting concentrations of mercury, lead, or cadmium at toxic levels. In most cases, control populations showed levels higher than those from mined areas. This suggested that surface mining actually reduced levels of available heavy metals in the soil.

Fowler and Adkisson[41] evaluated trees and shrubs to determine which were best suited for harsh conditions associated with surface mine spoil. Autumn olive (*Elaeagnus embellata*), elaeagnus cherry (*Elaeagnus multiflora*), arnot locust (*Robinia fertilis*), sawtooth oak (*Quercus acutissima*), red maple (*Acer rubrum*), and Toringo crabapple (*Malus sieboldi*) were recommended for quick improvement of habitat over a wide range of spoil acidity. Species not recommended were bush honeysuckle (*Lonicera tatarica*), barberry (*Berberis thumbergi*), Siberian crabapple (*Malus baccata*), Manchu cherry (*Prunus tomentosa*), American beautyberry (*Callicarpa americana*), bear oak (*Quercus ilicifolia*), highbush blueberry (*Vaccinium carymbosum* var.), rem-red honeysuckle (*Lonicera maackii*), and red cedar (*Juniperus virginiana*).

There have been recent investigations which focused on the application of treated sewage sludge on mined lands. Resulting data reflect such benefits as (1) an improved pH soil media, (2) a source of nutrients, and (3) improvement in physical condition of soil media.[42,43] However, selected studies revealed that heavy metals and other toxicity problems may arise.[44,45,46,47] Gaffney and Ellertson[45] investigated the amount of heavy metal uptake in redwinged blackbirds (*Agelaius phoeniceus*) and found that cadmium and lead seemed to pose a potentially serious hazard. They recorded concentrations of cadmium in kidney and zinc in liver tissues. However, no general broad-spectrum pattern of metal in concentrations was evidenced when brain, liver, and muscle were analyzed.

Research organizations are continuing to gather cost benefit information on applications of sludge to mined lands. If the facts support large scale use of treated municipal sludge to mined lands, part of the link of long sought control of nutrient cycling may become reality.

Although some abandoned mined lands reflect safety hazards and contribute to water pollution, a large percentage have revegetated naturally thereby reducing erosion and acid runoff. Many such lands have proven to be excellent wildlife habitat and have provided sport hunting and recreation for the public and habitats for non-game species. The future use of abandoned mine lands for fish and wildlife benefits needs close scrutiny by local, state, and federal government agencies.

Reclaiming land to original contour, especially land with established vegetation, destroys good wildlife habitat, may have severe adverse effects upon endangered or threatened species, and may re-create toxic conditions in the surrounding soil and water. Proposed rules and regulations for reclaiming abandoned mined lands generally address potential problems resulting from reclamation procedures (grading) by establishing specific criteria for selecting, assigning priorities to, and evaluating proposed reclamation projects. In addition, regional analysis and environmental impact assessments or statements will be developed under the supervision of the U.S. Department of the Interior, Division of Reclamation Planning and Standards, Abandoned Mine Lands Program and the U.S. Soil Conservation Service.

The potential of wildlife enhancement on abandoned mined land is significant and offers almost unlimited opportunities. The "wilderness" atmosphere created by these habitats provides a relief for city dwellers, while providing compensation and/or replacement for lost wildlife habitat. These already disturbed lands can contribute to the replacement of destroyed habitats without utilizing more "valuable" land deemed necessary for farming, housing, or industry. Future reclamation efforts should focus on major controlling factors where immediate maximum results can be obtained for fish and wildlife. One significant area involves the tolerance of wildlife reproduction to drastic disturbance of habitats.

Habitats of certain species are dwindling at accelerating rates in spite of an increased awareness of the need to preserve natural environments. Forty-seven species of wildlife became extinct in the United States between 1700 and 1970, with 25 lost within the last 50 years. Reintroductions of native species into former habitats may be an increasingly important strategy to help in the survival of wild animals and plants; successful efforts are already in evidence.[49] As noted above, a prime example is the giant Canada goose, now concentrated as a nesting population on surface-mined land in west-central Illinois. The most important factor contributing to its productivity is availability of diverse bodies of water and island nest sites; both resulted from surface mining activities and reclamation efforts.

Mined land is only a part of the habitat of many species. Through specific reclamation procedures, mined land can offer essential aspects of optimum habitat that may be lacking in neighboring land. Range extension could be one of many beneficial results.

The outlook for future reclamation of mined land for wildlife is optimistic. Advances have been achieved and new information is constantly being obtained. However, the amount of land involved is great enough to deserve proper and continuing attention. Even under the constraints of PL 95-87, sufficient variety of reclamation procedures are permissible which can and will contribute different end results. While these options have an enormous potential (for example, the introduction of endangered and/or threatened species, and proliferation of specific species for hunting and/or commercial purpose), responsible personnel should recognize that over-manipulation of any area may have a long-term adverse effect. Our country's original habitat was created through a lengthy natural selection process, and we should, therefore, use caution and foresight when making such important management decisions.

REFERENCES

1. U.S. Department of Agriculture. 1979. The status of land disturbed by surface mining in the United States. Soil Conservation Service. USDA. Washington, D.C. 124 pp.

2. Townsend, J. E., and R. J. Smith. 1977. Improving fish and wildlife benefits in range management. FWS/OBS-77/01. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 118 pp.
3. Deknatal, C. 1979. Wildlife Habitat development on private lands: A planning approach to rural land use. J. Soil and Water Conservation. November-December: 260-263.
4. Haynes, R. J., and W. D. Klimstra. 1975. Illinois lands surface mined for coal. Coop. Wildlife Res. Lab., S. Ill. Univ. Carbondale. 201 pp.
5. Russell, D. M. 1979. Problems encountered in promotion of fish and wildlife needs in the Surface Mining Act of 1977—Public Law 95-87. pgs. 47-49 *In* Surface mining and fish/wildlife needs in the eastern U.S. ADDENDUM to Proc. of a Symp. D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason, Jr., eds. FWS/OBS-78/81A. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 125 pp.
6. Tyus, H. M., and J. M. Lockhart. 1978. Mitigation and research needs for wildlife on western surface mined lands. pgs. 252-255 *In* The mitigation symposium: a national workshop on mitigation losses of fish and wildlife habitats. G. A. Swanson, Coord. General Tech. Rpt. RM-65. July 16-20, 1979. Colo. State Univ. Ft. Collins, Colo. 684 pp.
7. Dittberner, P. L. 1978. Rehabilitation of western wildlife habitat: A review. FWS/OBS-78/86. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 238 pp.
8. Streeter, R. G., R. T. Moore, J. J. Skinner, S. G. Martin, T. L. Terrell, W. D. Klimstra, J. Tate, Jr., and M. J. Nodle. 1979. Energy mining impacts and wildlife management: which way to turn. Presented at the 44th N. Amer. Wildl. and Nat. Resour. Conf. Toronto, Ontario, Canada March 26-28. 60 pp.
9. Evans, A. K., E. W. Uhleman, and P. A. Eby. 1978. Atlas of western surface-mined lands: Coal, uranium, and phosphate. FWS/OBS-78/20. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 260 pp.
10. Porter, L. R., G. W. Towns, L. W. Carlson, J. F. Hamill, and V. F. Fresquez. 1979. Promising methodologies for fish and wildlife planning and impact assessments. Region 6. Fish and Wildlife Service, USDI. Denver, Colo. 28 pp.
11. U.S. Fish and Wildlife Service. 1980. Habitat as a basis for environmental assessment. 101 Ecological Services Manual. Division of Ecological Services, Fish and Wildlife Service, USDI. Washington, D.C. 20240.
12. Salmen, L., J. Gropper, J. Hamill, and C. Reed. 1977. Natural resource geographic data bases for Montana and Wyoming. FWS/OBS-77-55. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 211 pp.
13. States, J. B., P. T. Haug, T. G. Shoemaker, L. W. Reed, and E. G. Reed. 1978. A systems approach to ecological baseline studies. FWS/OBS-78/21. Office of Biological Service, Fish and Wildlife Service, USDI. Ft. Collins, Colo. 211 pp.
14. U.S. Department of the Interior. 1979. Coal Lease Program. Washington, D.C. 20240.
15. U.S. Department of the Interior. 1979. Can coal development be compatible with fish and wildlife? The Bulletin Habitat Preservation News. 3(2):4-5.
16. Curry, R. B. 1975. Biogeochemical limitations on western reclamation. pgs. 18-47 *In* Practices and problems of land reclamation in western North America. M. K. Wali, ed. The Univ. of N. Dakota Press. Grand Forks, N.D. 196 pp.
17. Gould, W. L., D. Rai, and P. J. Wierenga. 1975. Problems in reclamation of coal mines spoils in New Mexico. pp. 107-121. *In* Practices and problems of land reclamation in western North America. M. K. Wali, editor. The Univ. of N. Dakota Press. Grand Forks, N.D. 196 pp.

18. Morgan, R. L. 1973. Environmental impacts of surface mining: the biologist's viewpoint. pp. 61-71 *In* Some environmental aspects of strip mining in North Dakota. M. K. Wali, ed. 121 pp.
19. Denver Wildlife Research Center. 1979a. Pronghorn response to coal mine construction. pp. 114-115 *In* Fisheries and wildlife research. 1978. T. G. Scott, P. H. Eschemeyer, and H. C. Schultz. Fish and Wildlife Service, USDI. U.S. Govt. Printing Office. Denver, Colo. 170 pp.
20. Boyum, B. H., F. A. Stormer, and S. G. Shetron. 1978. An ecological perspective of reclamation. Presented at the 3rd Annual General Meeting of the Canadian Land Reclamation Association. 29 May-1 June. Sudbury, Ontario, Canada. 13 pp.
21. Herricks, E. E., and M. J. Sale. 1978. Preplanning mining operations for mitigation of impacts on fish and wildlife resources. pp. 69-75 *In* Surface mining and fish/wildlife needs in the eastern United States. D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason. Proc. of a Symp. FWS/OBS-79/81. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.
22. Pentecost, E. D., and R. C. Stupka. 1979. Wildlife investigations at a coal refuse reclamation site in southern Illinois. pp. 107-118. *In* Surface mining and fish/wildlife needs in the eastern U.S. D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason, Jr., editors. ADDENDUM to Proc. of a Symp. FWS/OBS-78/81A. Office of Biological Services,Fish and Wildlife Service, USDI. 125 pp.
23. Urbanek, R. P. 1976. Vertebrate and floral diversity on strip-mined land in Williamson and Saline Counties, Illinois. Unpublished M.A. Thesis, S. Ill. Univ. Carbondale. 146 pp.
24. Grandt, A. F. 1976. Reclamation policies and techniques. Ill. Coal; Proceedings of the 4th Annual Ill. Energy Conf. 14 pp.
25. Beyer, L. E. , R. E. Nickel, and J. A. Diaper. 1979. Surface mining and the natural environment: technical manual-phase II. Hittman Associates, Inc. Center for Energy Research. Lexington, Ky. 225 pp.
26. Kelcey, J. G. 1975. Industrial development and wildlife conservation. Environ. Conser. 2(2):99-108
27. Byrnes, W. R., and J. H. Miller. 1973. Natural revegetation and cost overburden properties of surface-mined coal lands in southern Indiana. pp. 285-306 *In* Ecology and reclamation of devastated land. Volume I. R. J. Hutnik and G. Davis, eds. Gordon and Breach. New York, N.Y. 538 pp.
28. Konik, J. 1980. Some physical, chemical, and biological characteristics of non-problem waters occurring on lands surface-mined for coal. Illinois Inst. Nat. Res. DOC NO. 80/14.
29. Stoner, P. J. E. 1980. An evaluation of mammal use on reclaimed surface mined lands and unmined lands in two regions of Illinois. S. Ill. Univ. Carbondale. 132 pp. Unpublished.
30. Sandusky, J. E. 1978. The potential for management of waterfowl nesting habitat on reclaimed mined land. pp. 325-327. *In* Surface mining and fish/-wildlife needs in the eastern United States. D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason. Proc. of a Symp. FWS/OBS-79/81. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 386 pp.
31. Naurot, J. R., M. L. Fuson and D. M. Downing. 1981. Reedgrass and slurry pond reclamation. Mining Cong. J. 67(9):23-28.
32. Allaire, P. N. 1979a. Coal mining reclamation in Appalachia: low cost recommendations to improve bird/wildlife habitat. pp. 245-251 *In* The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats. G. A. Swanson, Technical Coordinator. General Tech. Rpt. RM-65. July 16-20, 1979. Colo. State Univ., Ft. Collins, Colo. pp.

33. Allaire, P. N. 1979b. The avifauna on reclaimed surface mined lands: its composition and role in land use planning. Ph.D. Diss., Univ. Louisville, Kentucky. 223 pp.

34. Byerly, D. W., J. B. Maddox, C. S. Fletcher, and D. T. Eagle. 1978. Reclamation of mined land in the Piney Creek watershed—an interim report. pp. 267-275 *In* Surface mining and fish/wildlife needs in the eastern United States. D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason, ed. Proc. of a Symp. FWS/OBS-79/81. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.

35. Curtis, R. L., D. K. Fowler, C. H. Nicholson, and L. F. Adkisson. 1978. Breeding bird populations on three contour surface mines reclaimed under differing intensities and types of treatment. pp. 369-375 *In* (See Ref. 33.) D. E. Samuel, J. R. Stauffer, C. H. Hocutt, and W. T. Mason.

36. Heine, W. N. 1978. Permanent regulatory program implementing Section 501(b) of the Surface Mining Control and Reclamation Act of 1977. DRAFT E. S. Office of Surface Mining Reclamation and Enforcement, USDI. Washington, D.C.

37. Whitmore, R. C., and G. A. Hall. 1978. The response of passerine species to a new resource: Reclaimed surface mines in West Virginia. American Birds. 32(1):6-9.

38. Yahner, R. H., and J. C. Howell. 1975. Habitat use and species composition of breeding aviguana in a deciduous forest altered by strip mining. J. Tenn. Acad. Sci. 50(4):142-147.

39. Holland, F. R. 1973. Wildlife benefits from strip-mine reclamation. pp. 377-388. *In* Ecology and reclamation of devastated land. Volume I. R. J. Hutnik and G. Davis, eds. Gordon and Breach. New York, N.Y. 538 pp.

40. Tolin, W. A. 1975. Bioaccumulation of mercury, lead, and cadmium in wildlife inhabiting coal strip-mined areas in Perry, Noble, and Harrison counties, Ohio. Ohio Coop. Wildlife Res. Unit. Ohio State Univ., Columbus, Ohio. Q. Rpt. 29(1):24-26.

41. Fowler, D. K. and L. F. Adkisson. 1980. Survival and growth of wildlife shrubs and trees on acid mine spoil. Technical Note B37. TVA. Norris, Tenn. 49 pp.

42. Stucky, D. J., and T. S. Newman. 1977. Effects of dried anaerobically digested sewage sludge effects on yield and element accumulation in tall fescue and alfalfa. J. Environ. Qual. 6(3):271-274.

43. Hook. L. A. 1979. Effects of copper, zinc, and cadmium on *Ictaluras natalis* resulting from sewage sludge reclamation of strip mined land. M.A. Thesis, S. Ill. Univ., Carbondale, Ill. 139 pp.

44. USEPA with the assistance of Enviro Control, Inc. 1976. DRAFT EIS for sludge disposal and land reclamation in Fulton County, Illinois.

45. Gaffney, G. R., and R. Ellertson. 1979. Ion uptake of redwinged blackbirds nesting on sludge-treated spoils. pp. 507-517. *In* Proc. of the Symp. on Municipal Wastewater Treatment. Penn. State Univ. Press, Philadelphia, Pa.

46. Williams, B. D., and P. E. Packer. 1977. Sewage sludge and other organic materials as amendments for revegetation of spent oil shale. pp. 353-358 *In* Proc. Symp. on Rehabilitation of Drastically Disturbed Land. Penn. State Univ. Press, Philadelphia, Pa.

47. Williams, P. H., J. S. Shenk, and D. E. Baker. 1978. Cadmium accumulation by meadow voles (*Microtus pennsylvanicus*) from crops grown on sludge-treated spoil. J. Environ. Qual. 7(3):450-454.

48. U.S. Environmental Protection Agency. 1980. Utilization of municipal wastewater and sludge for land reclamation and biomass production. Symp. Proc. (In prep.). September 16-18, 1980. Pittsburgh, Pa. Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C.

49. Botkin, D. B. 1977. Strategies for the introduction of species to damaged ecosystems. pp. 241-260 *In* Recovery and restoration of damaged ecosystems. J. Cairns, K. L. Dickson, and E. E. Herricks, eds. Proc. of a Symp. March 23-25, 1975. University of Virginia Press, Charlottesville, Va. 531 pp.

RECLAMATION OF WETLANDS

Mary C. Landin and Hanley K. Smith

BACKGROUND

The early colonists who came to American shores found pristine lakes and rivers, virgin forests, abundant wildlife, and vast wetland areas. They immediately set about to "tame" and change these lands to suit the purposes of civilization as they knew it. Throughout the settlement of this nation and until very recently, wetlands were considered wastelands to be converted to other more economically advantageous uses. The term "reclamation of wetlands" was synonomous with draining, clearing, and filling for agriculture and other endeavors. In this decade, "reclamation" has come to mean the restoration of disturbed wetlands to their former condition, or the development of new wetlands where none had previously existed.

The U.S. Soil Conservation Service (SCS) has estimated that there were 51,435,000 hectares (127,096,000 acres) of wetlands in the lower 48 states prior to settlement by Europeans.[1] The extent of these wetlands steadily declined until 1954, when the U.S. Fish and Wildlife Service (FWS) reported an estimated 30,132,000 hectares (74,456,172 acres) remaining.[2] Since 1954 destruction or degradation of existing wetlands has taken place at a rapid pace, especially in such regions as the lower Mississippi Valley, the prairie potholes, and in coastal marshes and estuaries.[3] These losses have occurred despite federal and state efforts to protect wetlands and the growing awareness of wetland values by private citizens.

An example of the wetland losses the nation has suffered in recent years was presented by MacDonald et al.[4] for the Mississippi River valley from southern Illinois to the Gulf of Mexico. Of 10,125,000 hectares (25,018,875 acres) originally in forested wetlands, only 2,097,900 hectares (5,183,911 acres) remain. Of that which remains, approximately 121,500 hectares (300,226 acres) of forested wetlands are cleared annually.

FEDERAL WETLANDS RESEARCH, DEVELOPMENT, AND PROTECTION PROGRAMS

The decline in the nation's wetlands has prompted the establishment of various federal programs aimed at either protecting or building wetland areas and involving substantial research efforts. For example, Executive Order 11990 in 1977 required that all federal agencies conserve and protect wetlands in all of their undertakings.

The U.S. Department of Agriculture's Water Bank Program is paying farmers in 15 states to leave wetlands and adjacent lands undrained and undisturbed (Ramon Callahan, SCS, Jackson, MS, personal communication). To date, 239,098 hectares (590,811 acres) are under 10-year agreements; 65,730 hectares (162,419 acres) are actual wetland areas, while 173,368 hectares (428,392 acres) are adjacent wetland habitats.

The Authors: Mary C. Landin is a wildlife biologist with the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. Ms. Landin's recent research interests include marsh restoration, the development of waterbird nesting habitat on dredged material islands, and borrow pit habitat evaluation.

Hanley K. Smith is an ecologist with the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Mississippi. Dr. Smith joined the Corps of Engineers in St. Louis before joining WES in 1974. His recent research interests include marsh development and wetland identification and delineation.

The FWS has several ongoing programs involving management and acquisition of wetlands. The two primary funding sources are: the Migratory Bird Conservation Fund Act, and the Land and Water Conservation Fund Act (J. W. Hardy, FWS, Vicksburg, MS, personal communication). The major agency objective is wetlands preservation through a variety of federal, state, and private land control mechanisms. Many hectares have been preserved and many others are planned for inclusion under a wide variety of FWS wetland habitat preservation activities. A majority of these lands are under the control of the National Wildlife Refuge System, and total more than 4 million hectares (9.9 million acres) covering many wetland types.[5]

While there are no titled programs as such, the National Park Service, the Forest Service, and the National Marine Fisheries Service also are managing and protecting wetland areas under their control.[3] Each agency is providing for implementation of wetlands policy according to its own authority and mission.

The U.S. Army Corps of Engineers (CE) and the U.S. Environmental Protection Agency (EPA) are jointly charged with the responsibility of regulating the discharge of dredged or fill material into the waters of the U.S. Both agencies have developed wetlands research programs and are actively involved in the implementation of the 404 Regulatory Program.

Because the CE is required to perform many dredging projects in order to maintain navigation, and because many million cubic meters of dredged material must be disposed of yearly, often within wetland areas, the agency carried out the $32 million, 5-year Dredged Material Research Program (DMRP). The DMRP concluded in 1978 after accumulating a wealth of information concerning environmental aspects of dredged material disposal.[6] Part of this program addressed wetland creation and development using dredged material substrates. The Dredging Operations Technical Support (DOTS) Program was initiated after the DMRP to provide assistance to the CE districts and divisions (and others related to CE activities) in using DMRP results. DOTS also includes continued monitoring of selected wetland development field sites and wetland criteria development. DOTS is managed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

Other CE programs involving wetlands research, but not necessarily development and protection, are the Environmental and Water Quality Operational Studies Program, which studies freshwater aquatic, riverine, lake, and marsh habitats (managed by WES); the Wetlands Research Program (managed by WES), which is providing wetlands criteria assistance to CE districts and divisions in the identification and delineation of wetlands; the Recreation Research Program (managed by WES); the Environmental Action Program (managed by the Institute of Water Resources, Fort Belvoir, Virginia); and the Coastal Ecology Program (managed by the Coastal Engineering Research Center, Fort Belvoir, Virginia). Section 150 of the Public Law 94-587 authorizes the CE to plan and establish wetland areas as a part of authorized water resources development projects.

WETLANDS HABITAT DEVELOPMENT

The concepts and practices of habitat development have evolved from protection of existing habitats, through planting food crops and water elevation control for waterfowl, to construction of wetlands where none previously existed. Presently, the art of building new wetlands or restoring previously disturbed wetlands is fairly well advanced, and is being practiced in locations throughout the United States.

State Efforts

The development and management of wetlands by the states has historically involved game animals that included wetlands as part of their habitat requirements; however, in recent years increasing attention has been paid to a wide range of wetland values. Among many notable examples of recent wetlands research and management are the efforts of the State of Michigan to preserve and improve remaining wetlands while reestablishing lost marshes.[7]

Private Efforts

Private groups such as Ducks Unlimited, Inc., and the National Audubon Society have substantial amounts of wetlands under their control. Such areas are often protected as sanctuaries and preserves in a total ecosystem management approach. Many of these areas were acquired over the last decade, as the private citizen's responsibility for endangered and threatened wildlife and wetlands has increased. Additionally, dedicated commercial and nonprofit companies undertake by contract to build wetlands. The most prominent of these companies, Environmental Concern of St. Michael's, Maryland, has built numerous salt marshes along the Atlantic coast with a great deal of expertise and efficiency. Other notable companies in this field are: Mangrove Systems, Inc., of Tampa, Florida, Wave Beach Grass Nurseries of Florence, Oregon, and San Francisco Bay Marine Research Center of San Francisco, California. Personnel of these companies have traveled extensively to accomplish their wetlands-building missions.

Federal Agencies

FWS Efforts

The FWS has expanded its traditional objectives of management for wildlife species (primarily waterfowl) to include a total ecosystem approach.[3] As previously noted, FWS expends much of its resources on acquisition, protection, and management of the National Wildlife Refuge system. There are 460 waterfowl areas and migratory bird refuges located throughout the United States, each centered around a unique or valuable habitat for one or more species of wildlife.[5] Most of these areas include wetland communities.

The FWS has conducted wetland studies through projects such as the National Wetlands Inventory and the Habitat Evaluation Procedures, and through research into habitat classification, coastal ecosystems and stream alterations.[8] Basic wetlands research is being conducted by the Patuxent Wildlife Research Center, the Migratory Bird Research Laboratory, the Denver Wildlife Research Center, the Northern Prairie Research Center, and the cooperative wildlife research units in many states, plus other FWS research activities scattered across the United States.

CE Efforts

The CE has focused its wetlands development research efforts primarily in the DMRP/DOTS programs. The DMRP Habitat Development Project conducted extensive literature surveys on the subject, and demonstrated innovative marsh establishment techniques at six major sites around the United States: Windmill Point, Virginia; Buttermilk Sound, Georgia; Apalachicola Bay, Florida; Bolivar Peninsula, Texas; San Francisco Bay, California; and Miller Sands Island, Oregon. Materials and methods used to develop these field sites as well as interim results of site establishment are set forth in a series of technical reports available from WES.[9-15] A series of synthesis reports also include detailed information on wetland habitat development, management, ecological considerations, wildlife use, costs, engineering techniques, and other pertinent factors.[16-20] The techniques set forth in these reports were designed specifically for dredged material substrates; however, they can be readily applied to other disturbed substrates as well. Applications have already been made to a strip mining site[21] and could apply equally well to other mining sites, road fill and borrow areas, construction sites, reservoir drawdown zones, and eroding shorelines and banks.

BUILDING A WETLAND

The procedures and techniques employed by the CE in the development of a wetland are described in the following paragraphs. A more detailed account of the items discussed can be found in the referenced reports. This discussion pertains to the construction of a wetland where none previously existed. Most such situations involve the use of fill material.

A wetland may be built for a number of reasons, including mitigation of wetland destruction, prevention of erosion, shoreline or bank stabilization, and reclamation of an existing disposal or construction site to increase its wildlife value. A wetland may be used alone as a singular habitat or built in conjunction with aquatic, upland, or island habitat. It may also be used to introduce a new type of habitat into an area, where previously little or none of that type had occurred.

Once an initial decision has been made to build a wetland, there are three major phases necessary to the successful establishment: planning, engineering, and plant propagation.[17]

PLANNING

Many types of wetlands can be developed, including intertidal salt and fresh marsh, semipermanently flooded fresh marsh, riverine or lake habitat, and shrubby and forested wetlands. Techniques discussed here are sufficiently general to apply to most situations, but the reader is urged to consider each site as unique and worthy of the site-specific considerations set forth in references 16, 17, and 20.

Site Selection

Site selection should be based on a number of factors including the availability, accessability, size, physical and engineering features, environmental and social acceptability, and tidal, current, wind, and wave considerations.

Site Characterization

Once a site has been tentatively selected, the need for more precise physical and biological information becomes necessary. Key environmental considerations often consist of public attitudes, aesthetics, loss of open-water habitat, changes in the energy and hydrologic regime, and pollutant mobilization. Substrate characteristics at the site and characteristics of the material to be placed on the site should also be determined. Site configuration, topography, elevation, and size should be identified, so that adjustments can be planned and made if necessary. Existing wildlife and plant species on and adjacent to the site should be noted, as these are probably the species that will colonize the newly built wetland. Water regimes should be understood so that necessary protection can be provided. Measurements of substrate stability should be made, and the availability of materials for any necessary dikes or retaining structures should be determined.

Special Considerations

The legalities of creating a wetland are often complicated and vary from state to state. There are a number of Federal and state laws that come into play and involve zoning, endangered species, water quality, transport of plant material, ownership of property, disruption of existing habitat, and other regulations and considerations. Other common concerns include the needs and desires of local residents, construction agency authorization, and project costs.

ENGINEERING

The project engineer must have accurate information on the volume and engineering characteristics of the fill material, the foundation characteristics of the site, and the local hydrologic forces. The project design should consider a wide range of factors including salinity, bottom topography, equipment availability, transport distances, and project schedules.

Weirs, retaining structures, and dikes to protect the site should be designed to best suit the wetland to be built. This could range from no structure in a very low energy area, to a temporary sand dike enclosing the wetland until it becomes established, to a permanent riprap dike around an area of very high energy.

If dredged or fill material is used at the site, care should be taken to place the material at desired elevations or to shape it after it is in place. If hydraulically pumped material is used, consolidation rates must be calculated accurately or the completed site could be either above or below the desired wetlands elevation. Much of this work can be accomplished by moving the disposal pipe at intervals and/or by using heavy equipment to shape the site. Special dredging technology exists that can be used for placement of dredged material to a specified elevation.[22,23]

PLANT PROPAGATION

The biological aspects of wetland development include selection of propagules, preparation of soil to receive propagules, actual plant establishment, and monitoring to determine plant survival.[17] Sketches of typical plant associations based on elevation and water level in wetlands of various regions of the United States are shown in Figures 1-4.

Soil Bed Preparation

Soil tests for texture, salinity, nutrients, heavy metals and other contaminants, and pH should reveal any need for changes in the soil chemistry. Fertilization is frequently recommended. Grading may be necessary to ensure proper elevations. In sandy or well-drained soils, grading usually presents no problem; however, grading by conventional means is usually impossible on silt and clay soils. In the latter situation elevation changes may be made through use of high-pressure hoses or pipes. In any case, a well-prepared bed to receive propagules will help ensure site success.

Species and Propagule Selection

Salinity, tidal range, current and flood stages, soil texture, wind and wave action, contaminant tolerance, outside influences such as human disturbance and animal grazing, and costs are all factors that must be considered carefully when site vegetation is selected. Plant species should be selected to suit the project goal. They should be from a nearby location, adapted to local conditions, and readily available at a reasonable cost. They should be tolerant of site soil, climate, water, and contaminant conditions; have desirable growth characteristics; and have low maintenance requirements. The propagule type should be selected on the basis of availability; collecting, handling, storing, and planting ease; project goals; freedom from disease; need for immediate plant cover; and site elevation. Careful consideration should be given to cost. For example, sprigs are much more expensive than seeds for most species; however, sprigs are usually much more successful than seeds. There are situations, however, in which seeds are equally as effective as sprigs.

Planting Design

In general, it is desirable to encourage plant species diversity because many wetlands are naturally diverse; diversity will aid if one species dies but others survive. Diversity of habitats will encourage diversity of wildlife.

Spacing of plant propagules is very site specific and depends upon factors such as the soil texture, type of propagule, length of growing season, energy regime, and desired rate of plant cover. Planting with about a 1-m spacing is generally a good compromise between high costs and adequate cover, but spacing of 0.3 to 1.5 meters may be successfully used in many instances. Costs increase dramatically with closer spacing. If a site is very unstable or is subject to heavy wildlife pressures or physical

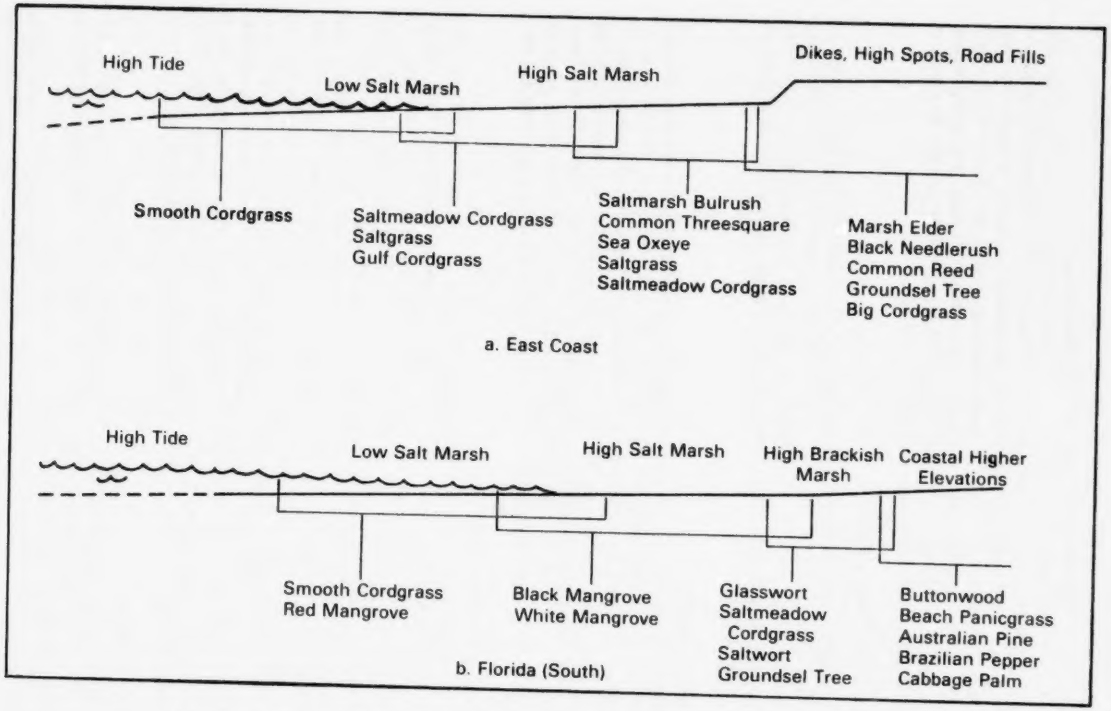
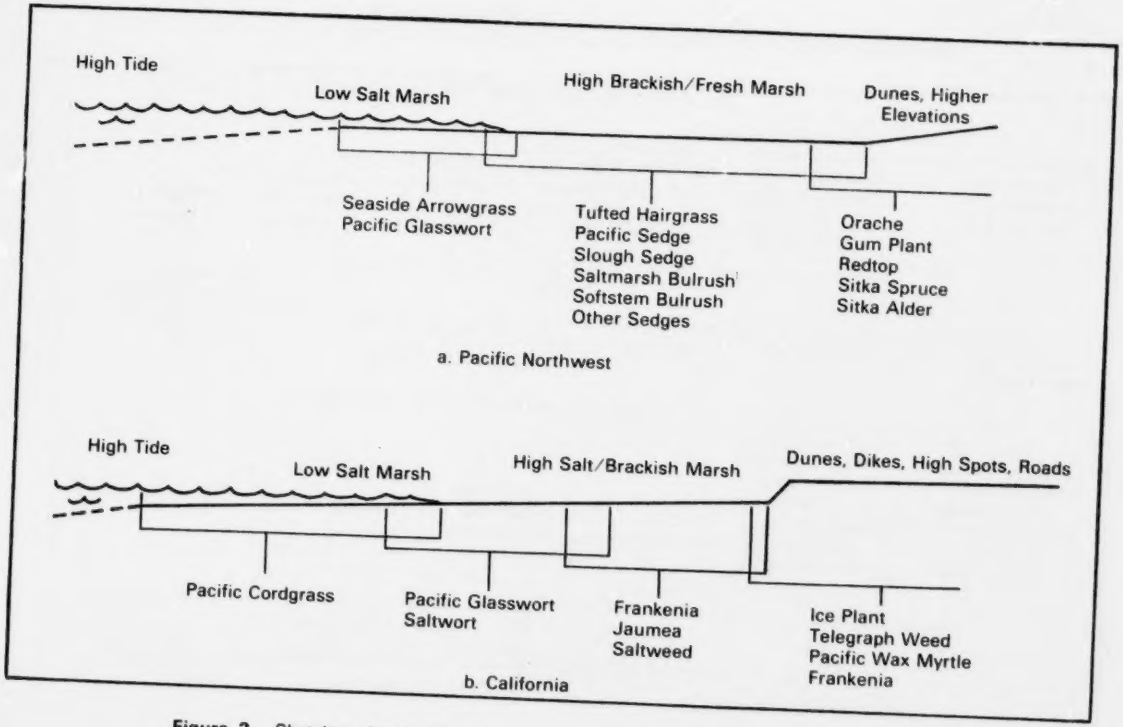


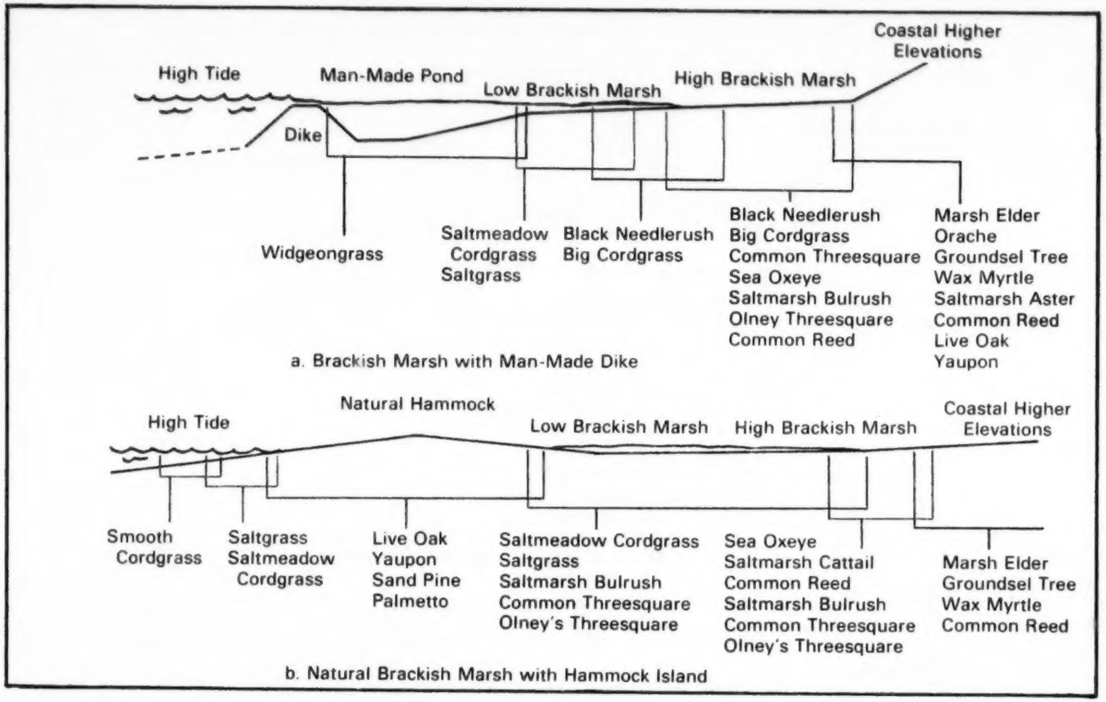
Figure 1. Sketches of typical east coast and Florida tidal marshes showing plant associations and usual occurrence in the wetlands.



a. Pacific Northwest

b. California

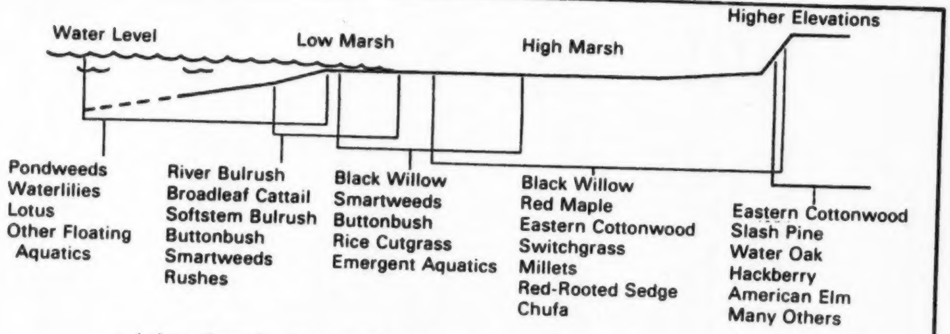
Figure 2. Sketches of typical Pacific Northwest and California Coast tidal salt marshes showing plant associations and usual occurrence in the wetlands.


High Tide
Man-Made Pond
Low Brackish Marsh
High Brackish Marsh
Coastal Higher Elevations
Dike
Widgeongrass
Saltmeadow Cordgrass Saltgrass
Black Needlerush Big Cordgrass
Black Needlerush Big Cordgrass Common Threesquare Sea Oxeye Saltmarsh Bulrush Olney Threesquare Common Reed
Marsh Elder Orache Groundsel Tree Wax Myrtle Saltmarsh Aster Common Reed Live Oak Yaupon
High Tide
Natural Hammock
Low Brackish Marsh
High Brackish Marsh
Coastal Higher Elevations
Smooth Cordgrass
Saltgrass Saltmeadow Cordgrass
Live Oak Yaupon Sand Pine Palmetto
Saltmeadow Cordgrass Saltgrass Saltmarsh Bulrush Common Threesquare Olney's Threesquare
Sea Oxeye Saltmarsh Cattail Common Reed Saltmarsh Bulrush Common Threesquare Olney's Threesquare
Marsh Elder Groundsel Tree Wax Myrtle Common Reed

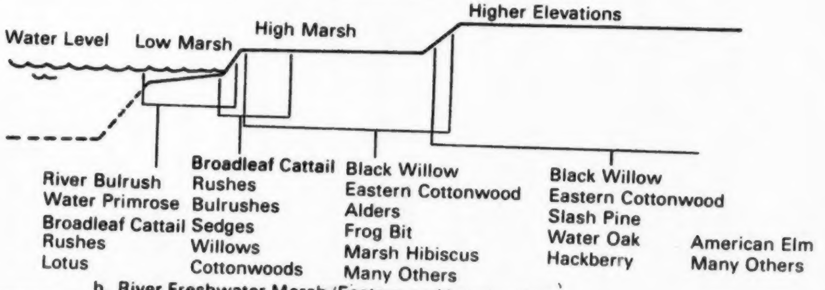
a. Brackish Marsh with Man-Made Dike

b. Natural Brackish Marsh with Hammock Island

Figure 3. Sketches of typical brackish marshes, showing plant associations and usual occurrence in the wetlands.



a. Lake or Pond Freshwater Marsh (Eastern and Interior U.S.)



b. River Freshwater Marsh (Eastern and Interior U.S.)

Figure 4. Sketches of typical lake or pond and river freshwater wetlands showing plant associations and usual occurrence in the wetlands.

stress, or if aesthetics are of real concern, more dense plantings of herbaceous plants are recommended. When trees are part of the wetland development scheme, they must be adequately spaced (2 to 5 meters) to survive and grow properly. To reduce stress and washout, the young trees may be surrounded by a planted herbaceous marsh to give them temporary protection. For example, smooth cordgrass is planted in Florida to act as a buffer for mangrove transplants and seed pods, and serves until the mangroves take root and crowd out the grass (R.R. Lewis III, Mangrove Systems Inc., Tampa, Florida, personal communication).

Planting Schedule

In general, plants may be established at any time the ground is not frozen. However, spring months (April-May) are usually best because the propagules will have an entire growing season to establish a good root system prior to winter dormancy. Biological preparations such as gathering and storing propagules should take place while the engineering phase is being completed. An entire growing season can be missed if proper preparations are not made in a timely manner.

Pilot Study

A pilot study should precede large, costly wetland projects, or projects in which site conditions make success less than certain. The pilot study is a small-scale version of the larger project, and should be designed to anticipate problem areas prior to full-scale construction.

Natural Colonization

If the cost of planting a wetland is prohibitive, the site may be prepared at an appropriate elevation and natural colonization allowed to take place. Natural colonization may take only a few months in the case of freshwater wetlands, or it could take as long as 10 years in salt marshes. The major disadvantages to natural colonization are that undesirable plant species may invade the site or the site may be washed away before plants can provide stabilization.

Monitoring

A site should be monitored after planting to determine species survival, plant growth, site changes, and succession. At a minimum, monitoring efforts should note site succession, species diversity, productivity, wildlife use, and changes in elevation and substrate conditions.

Problems

Some of the more common problems in wetland development are: lack of coordination between engineering and biological personnel, project/planning mis-timing, incorrect selection of plants and propagules, contaminant uptake into plant shoots that wildlife may consume, invasion of undesirable plant species, pest wildlife and feral animals on a site, plant diseases that may be introduced to a site, and cost.

SUMMARY

America's wetlands are disappearing at an alarming rate, but private citizen and public agency actions reduced the annual destruction rates to some degree during the 1970-1980 decade. Wetland protection and management are essential to maintain the health, vigor, and usefulness of our wetlands. Wetland development may be used to enhance or improve existing wetlands, to build wildlife habitat, or to build wetlands where insufficient areas previously existed. Technology is developed and available for use in wetland construction of all types, and the expertise is available upon request from such agencies as the CE and the FWS.

REFERENCES

1. U.S. Department of Agriculture. 1938. Soils of the United States. USDA Yearbook. Washington, D.C.
2. Shaw, S. P., and G. C. Fredine. 1956. Wetlands of the United States. Circular 39. Fish and Wildlife Service, USDI. Washington, D.C. 67 pp.
3. Horwitz, E. L. 1978. Our nation's wetlands. Council on Environmental Quality Interagency Task Force Report. Washington, D.C. 70 pp.
4. MacDonald, P. O., W. E. Freyerm, and J. K. Clauser. 1979. Documentation, chronology, and future projections of bottomland hardwood habitat losses in the lower Mississippi alluvial plain. Vol.I and II. Fish and Wildlife Service, USDI. Vicksburg, Miss.
5. U.S. Fish and Wildlife Service. 1976. Operation of the National Wildlife Refuge System. Final Environmental Impact Statement. Washington, D.C.
6. Saucier, R. T., C. C. Calhoun, Jr., R. M. Engler, T. R. Patin, and H. K. Smith. 1978. Executive overview and detailed summary of the Dredged Material Research Program. TR DS-78-22. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
7. Landin, M. C. 1979. Marsh restoration and habitat development using dredged material substrates at Pointe Mouillee State Wildlife Area in Lake Erie, Michigan. Dredging Operations Technical Support Report (unpublished) to the U.S. Army Corps of Engineers, Detroit District. Detroit, Mich.
8. U.S. Fish and Wildlife Service. 1978. Biological Service Program. FWS/OBS-79/26. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C.
9. Hunt, L. J., B. R. Wells, and A. W. Ford. 1978. Habitat development field investigations, Nott Island upland habitat development site, Connecticut River, Connecticut: summary report. TR D-78-25. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
10. Lunz, J. D., T. W. Ziegler, R. T. Huffman, B. R. Wells, R. J. Diaz, E. J. Clairain, Jr., and L. J. Hunt. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia: summary report. TR D-77-23. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
11. Cole, R. A. 1978. Habitat development field investigations. Buttermilk Sound marsh development site, Georgia Intracoastal Waterway, Georgia: summary report. TR D-78-26. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
12. Kruczynski, W. L., R. T. Huffman, and M. K. Vincent. 1978. Habitat development field investigations, Apalachicola Bay marsh development site, Apalachicola Bay, Florida: summary report. TR D-78-32. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
13. Allen, H. H., E. J. Clairain, Jr., R. J. Diaz, A. W. Ford, L. J. Hunt, and B. R. Wells. 1978. Habitat development field investigations, Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas: summary report. TR D-78-15. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
14. Morris, J. H., C. L. Newcombe, R. T. Huffman, and J. S. Wilson. 1978 Habitat development field investigations, Salt Pond No. 3 marsh development site, South San Francisco Bay, California: summary report. TR D-78-57. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
15. Clairain, E. J., Jr., R. A. Cole, R. J. Diaz, A. W. Ford, R. T. Huffman, L. J. Hunt, and B. R. Wells. 1978. Habitat development field investigations, Miller Sands marsh and upland habitat development site, Columbia River, Oregon: summary report. TR D-77-38. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.

16. Lunz, J. D., R. J. Diaz, and R. A. Cole. 1978. Upland and wetland habitat development with dredged material: ecological considerations. TR DS-79-15. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
17. Environmental Laboratory. 1978. Wetland habitat development with dredged material: engineering and plant propagation. TR DS-78-16. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
18. Hunt, L. J., M. C. Landin, A. W. Ford, and B. R. Wells. 1978. Upland habitat development with dredged material: engineering and plant propagation. TR DS-78-17. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
19. Soots, R. F., Jr., and M. C. Landin. 1978. Development and management of avian habitat on dredged material islands. TR DS-78-18. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
20. Smith, H. K. 1978. An introduction to habitat development on dredged material. TR DS-78-19. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
21. Landin, M. C. 1979. Restoration of wetlands habitat on Gifford-Hill Mining Company lands in northwestern Louisiana. Dredging Operations Technical Support Report (unpublished) to U.S. Army Corps of Engineers, New Orleans District. New Orleans, La.
22. Eckert, J. W., M. L. Giles, and G. M. Smith. 1978. Design concepts for inwater containment structures for marsh habitat development. TR D-78-31. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Miss.
23. Landin, M. C., and R. L. Montgomery. 1980. Feasibility of salt marsh smothering with dredged material at Cedar Point, Georgia. Dredging Operations Technical Support Report (unpublished) to the U.S. Army Corps of Engineers, Savannah District. Savannah, Ga.

ECOLOGICAL SCIENCE AND TRANSMISSION LINE RIGHTS-OF-WAY—A DECADE OF INNOVATION, ADJUSTMENT AND STRAIN

Jeffrey A. Davis

Perhaps the greatest disgrace of man's tenure on Earth has been his treatment of the planet's green mantle, the plant cover that sustains all animal life. Modern man is not solely responsible. This improvidence dates back some 10,000 years to the agricultural revolution when *Homo sapiens* began planting and herding organisms successfully enough that food surpluses allowed the concentration of societal wealth, lessened mortality rates, and improved natality. From that time on the chopping, burning, plowing, overgrazing and now over-spraying have resulted in the denudation, erosion, siltation, and biotic impoverishment that are well known to any conservation historian.

The idea that landscapes might have a mosaical covering of artificial, semi-natural, and natural plant communities manipulated according to a science of Vegetation Management to produce a balanced production of food, forage, timber, pure water, wildlife habitat, and environmental amenities is relatively new. Paradoxically, the concept is a creation of modern Technologic Man, the villain in so many tales of woe.

This article will discuss the idealistic concept of Vegetation Management as it applies to one particular domain of land, the nation's immense network of gas and electric transmission line rights-of-way (ROW) which require vegetation control to insure their efficient operation. In this survey, we will also see how ROW concerns broadened dramatically in the 1970s, producing gratifying successes and disillusioning failures.

First, we need to ask: do utility ROWs warrant our worry? Are the issues significant enough to justify involvement by ecologists? Assuredly yes, if one considers the amount of land now devoted to this purpose. Recent estimates[1] put the figure at some 5 million acres for lines 115 Kv (kilovolts) and above; and some project the addition of about 7 million more ROW acres by the year 2000.[2] No one knows how much greater these figures would be if subtransmission lines (34.5 to 69 Kv), and gas pipelines were added in. Perhaps we are talking about a total land area five or six times the size of Connecticut.

A CONCEPT OF ROW MANAGEMENT

This article accentuates mainly mission-oriented research—research carried out in hopes of improving management. The satisfactions and delights of purely intellectual

---

The Author: Jeffrey A. Davis is a Research Fellow at Aton Forest, a privately endowed ecosystem research station in NW Connecticut where he aspires to develop a "Biocommunity Science" integrating concepts from the fields of Wildlife and Vegetation Science. He has served four years (1965-1969) as a game biologist for the Ohio Division of Wildlife, and two years (1970-1972) as wildlife biologist for the National Audubon Society in Millbrook, N.Y., and served seven years as senior terrestrial ecologist for the NYS Public Service Commission (Office of Environmental Planning) in Albany.

pursuits are sacrificed. To evaluate a decade of applied research there must be a frame of reference, explicit statements of management objectives. Within such a frame of reference, research can be pursued by *scientists* to provide better knowledge and methods to help *managers* overcome obstacles to their goals.

The best statement of goals is this: ROW management for the lowest costs, for the most years, within the engineering needs, with the highest conservation values.[3] This is merely a call for efficiency in the delivery of services without harm to (and possibly actually benefiting) the environment. This was a revolutionary idea in the 1950s, and remains so today in some quarters, because it was applied to a situation in which a "state of war" existed. The battleground was ROWs where resurging resilient brush was pitted against the attacks of stubborn men. The utility engineers were using herbicides, their newest technologic weapon. The brush fought back with stone age "tools," genetic adaptability acquired through a million-plus years of natural selection.

The following statement of objectives in one form or another has been widely adopted among those utilities that have bothered to formulate ROW policies. The concept, because of its importance as a research and management framework, deserves a closer look.

Contemporary ROW management is more than just "brush control" to maintain line security. Society is asking the ROW manager (or utility forester) to be a *resource* manager. His job requires the creative artful application of scientific knowledge to achieve a number of goals:

1. Maintenance of line security and reliability. This involves keeping tall-growing vegetation out of the Wire Security Zone and maintaining adequate access to facilities.
2. Employment of vegetation control methods that have minimum adverse impact on the environment or on non-target organisms. This involves selecting from among alternatives a feasible method(s) that is compatible with a given set of environmental conditions.
3. Maintaining a methodological regime that, over the life of the line, results in the lowest *pro rata* cost for vegetation maintenance, thereby lessening the cost of energy to customers in the long run.
4. Employment of a methodological regime consistent with the above goals that, as an ancillary benefit, produces a vegetated environment that has high conservation value. This includes the development and maintenance of wildlife habitat, and the aesthetic, recreational, educational, and food and fiber values of the ROW resource to their highest practical levels.

In practice, it is unlikely that all these goals can be fully met simultaneously. In achieving one, certain aspects of others may be sacrificed; the task is a balancing act. This implies that the manager knows what environmental values justify modification of engineering specifications, because such plans are seldom altered without charge. Sometimes it is deemed necessary to relax economic standards (i.e., keeping costs down) in order to preserve a resource of uncommonly high worth. Making such trade-offs is subjective and interpretational, as is the handling of values; it involves cooperation, negotiations, disputes, and compromises with other specialists. There is no valid mathematical formula (nor is there likely to be) for "objectively" dealing with this web of dynamic factors. The degree to which ROW professionals solve these problems depends heavily on talent, interest, motivation—and on a proficiency with the Egyptian Equation. Now to research.

THE SCIENTIFIC QUEST

The Early Years

"No more research is needed . . . enough is already known radically to change existing policies, so as to effect both economies for the managing organization, and to increase conservation values . . ." So declared vegetation scientist Frank Egler in his controversial book *The Plight of the Right-of-Way Domain.*[3] Egler had held these views since the early 1950s. They pertained to the feasibility of developing low-growing communities of shrubs and herbs as cover on transmission ROWs. Such vegetation types are relatively stable (i.e., they do not readily change into grass or tree types). Thus, they are obviously superior to stands of fast-growing tree shoots that quickly intrude into overhead lines causing power outages, or to grassland in which undesired tree seedlings readily establish themselves.

Since the brush control methods then used did not give adequate root-kill of trees, maintenance had to be performed at frequent intervals. In contrast, low-growing (usually < 15 ft. tall) and relatively stable shrub communities need less maintenance over the life of the line. Therefore, dollars are saved. Moreover, ROWs rich in bushes and small trees are productive of berries, nuts, drupes and pomes, and thus make good wildlife habitat.

In his remark about research, Egler was criticizing industry for not taking advantage of existing scientific information on plant and animal ecology, but was not suggesting that *all* was known. Theories of vegetation change (i.e., plant succession) remain highly pertinent to ROW research and management. Because of this, and because they demonstrate the important role that academic plant ecology played in the development of this field, a brief review is warranted.

The initial reaction of managers and ecologists generally to the idea of low-maintenance shrub communities was: "nonsense." The theory of the period, which had become dogma, was that shrubs were only a transitory stage in an orderly succession of communities culminating in a climax or "adult" forest. This theory, the creation of influential ecologist Frederick Clements, held that a site stripped of its trees would return to trees through an *orderly* sequence of "immature" stages: generally, (1) grassland, (2) herbland, (3) shrubland, (4) shade intolerant tree stage, and finally (5) climax forest—a specific association of species that could reproduce in its own shade (the other stages could not), hence perpetuating itself indefinitely. Let Clements himself, in his definitive work *Plant Succession and Indicators*,[4] describe his theory:

> The fundamental nature of the climax and its significance in the life-history of a vegetation are indicated by the fact that it is the mature or adult stage of a vegetation . . . The climax information is the fully developed community, of which all initial and medial communities are but stages of development . . . The explanation of the universal occurrence of a climax in succession lies in the fact that succession is reproduction. The reproduction process can no more fail to terminate in the adult form (climax) in vegetation than it can in the case of an individual plant.

Clements' concept left plenty of room for stalled stages within the progression, e.g., the subclimax and disclimax. Nevertheless, its core precept of a deterministic vegetation ontogeny akin to that undergone by an individual organism was ripe for exploitation by those who desired, for various reasons, to discredit or challenge the heresy of "natural" shrub-herb communities that were relatively stable and easy to keep that way. Accordingly, a sound management concept stagnated for years. This fascinating episode is of interest because it reveals how basic human propensities enter into the development and flow of knowledge, thus greatly affecting ideals of research, management, and societal good.

Contrary to the beliefs of many early workers there were (and are) numerous examples of vegetation types with "neotenic" qualities: the grassy balds and scrubby slicks of the southern Appalachians, the heath barrens of the Coastal Plain, and the chaparral types of California's Encinal (oak) Province. In fact such communities may be seen everywhere, when one only looks; *Viburnum, Salix, Cornus, Kalmia, Rhododendron, Solidago,* and ferns form them in the east; in the west, *Berberis,* *Symphoricarpos, Ceanothus, and Arctostaphylos* are likely candidates. More important to our utilitarian interests is the ease by which such thickets and colonies, if intergrown with trees, can be converted to pure shrub-herb types lasting for decades. This is best accomplished by stem-specific removal (*in situ* root killing) of trees within the shrub clumps. Once removed (without baring the soil) by such techniques as selective basal spraying, trees do not readily reinvade.

Today's concerns about transmission lines involve more than just ROW vegetation management, however. The 1970s saw a burst of novel issues. New legislation, combined with new and bigger transmission lines, heightened public awareness. Into the scene moved lawyers, landscape architects, environmental analysts, administrators, and scientific specialists (most of them *inexperienced*). Add to this population growth more avenues for public participation, more intra-species stress, and *less* "vacant" land, and we get a broadening and intensification of issues.

Now we hear about corona, ozone, electromagnetic force fields, and dioxins as threats to farms, public health, and wildlife. Engineers now design and paint poles to make them aesthetically less offensive. They experiment with new methods and equipment to lessen land impacts. Computer-based constraint maps are used to route new lines more wisely through the landscape. Watercourses and wetlands now receive attention as "ecologically-sensitive" areas. Popular game animals and rare and endangered species are also taken into account.

Quite likely these are all valid concerns. Certainly significant dollar sums have been expended on them. Some problems (e.g., ozone) have turned out to be non-problems, while others, such as certain herbicide residues, remain troublesome. In most cases the investigatory and mitigation benefits were (and are) assumed; cost accounting has been inadequate; thus we see few evaluations of benefits versus costs. It is my intuitive feeling that many of these issues are, or will prove to be, distractions from the most legitimate concern of transmission line ecology—ROW vegetation. This is because vegetation, due to its manageability, is directly or indirectly the key to the condition of other components (soil, water, wildlife) and processes (filtration, nutrient cycling, energy flow) of our corridor "ecosystems." Perhaps this opinion only reflects an ecologist's bias, and if I knew more about physics, chemistry and cell physiology I would accentuate pollutants and magnetic fields.

The Decade: 1970-1980

The following overview looks at the development of scientific knowledge within subject areas of high concern to ROW managers.

ROW Planning and Clearing

This work involved the development and implementation of concepts, strategies, and new techniques. It was research only in the sense of gaining experience with tools new to the field, e.g., the use of computers for route selection, or helicopters for transporting hardware and removing cut trees. The publication of scientific papers on these experiences in refereed journals was uncommon.

Computer advocates learned of a dearth of biological knowledge of our "average" landscape. They also discovered the weaknesses of text book models (e.g., wildlife population dynamics) when applied to long narrow corridors. The developers of route constraint maps found landscapes constraining indeed, a fact most apparent in the hearing room where each land-holder or land-protector had his say. Nonetheless, because of such innovations routing and construction were more sensitively done than ever before.

The disposal of forest residues left by ROW clearing was often heatedly debated. Each method had its protagonist; there were pilers, windrowers, chippers, and drop-and-lopers. Those favoring slashburning succeeded in getting some utilities (e.g., in New York) to make field measurements. Everyone learned about the perplexities of smoke measurement, and the many variables of topography, weather, and combustibility affecting scientific interpretations. It was also apparent to observers that smoke was not a significant pollutant or hazard in rural areas, when atmospheric circulation is good and the burn piles attended. Open burning should remain a slash-disposal option for well-trained managers to use according to their judgment, assuming that public attitudes and government air standards maintain or attain rationality.

Soil Impacts

Knowledge in this area is derived almost entirely from government resource management agencies and universities. Dailey's valuable bibliography[5] cited soils 92 times. Many of these were linked with herbicide residue studies. An examination of ROWs in New York State,[6] applicable to most of the humid Northeast, found soils little disturbed except along access roads and at tower locations. Between these loci, where most of the ROW lies, soils are usually protected by vegetation. Here, topsoil conditions did not differ from adjacent woods. This study, however, did not document line impacts on the Long Island Moraine where fragile substrates have taken a pounding (Figure 1).[a] Damage there is permanent, or could be corrected only by very costly restoration. However, the sociological context of this urbanized area makes such efforts "impractical," managers say.

Light, excessively-drained soils in other parts of the country undoubtedly show similar effects where ROW access is unmanaged. In mountainous regions the potential for accelerated erosion is also high. A Montana master's thesis[7] predicted that road construction associated with logging would be the principal source of stream sediments. Other investigators, such as Megahan and Kidd,[8] have proved this to be the case. In such rugged terrain some utility companies are turning to helicopters to erect structures, thus eliminating costly road requirements.

By and large, ROW soil impacts are not of high research priority. The first need is for better *application* of an already well-developed technology for erosion and sediment control, or for younger managers to gain field *experience* in the many techniques that they read about.

Stream Impacts

During environmental impact reviews, conservationists ask many questions of utility personnel about stream protection practices. Answers reveal that engineering and management techniques are plentiful but an examination of scientific literature shows technique evaluations to be sparse.

Government literature is valuable in assessing hazards to small streams from ROW construction. Daytime water temperatures can be significantly elevated (up to 8-10°F)[9] by shade removal, and poorly designed access roads can be a source of damaging silt.[10] These factors are especially threatening to salmonids. However, we seldom encounter anyone in transmission line work (biologist or manager!) who seriously worries about chubs, shiners, darters or dace—no matter how beautiful their colorful markings or how interesting their organized schools.

Several papers showed how culverts can block migrating fish.[11,12] Significant effects on fish movements must have occurred at hundreds of sites throughout the states, for utilities have installed thousands of culverts. But here again the supposed

---

[a] Figures 1a, b, and c show progressive development of ROW denudation and erosion problems in the Oak-Pine Zone, Long Island, N.Y., due to uncontrolled vehicular access.—(a) natural oak-pine forest with dense ground layer of ericads, mainly the desirable *Gaylussacia baccata* and *Vaccinium vacillans*; (b) ten year old (±) ROW on a similar site, but consisting of pitch pine regeneration. Shrubs (e.g., *Gaylussacia*) were dense in the adjacent woods; (c) an older ROW on similar site, with oak-pine-huckleberry forest adjacent. Note remanent patch of top-soil at bottom of picture.

Rights-of-way on eastern Long Island are "great places" for cross country dune-buggy safaris, which quickly destroy vegetation on these fragile sandy sites. Efforts to control such unauthorized access usually results in barricade (e.g., fence) crashing. A "classified" agency report (1979) suggested a sociological study and evaluation of the situation.

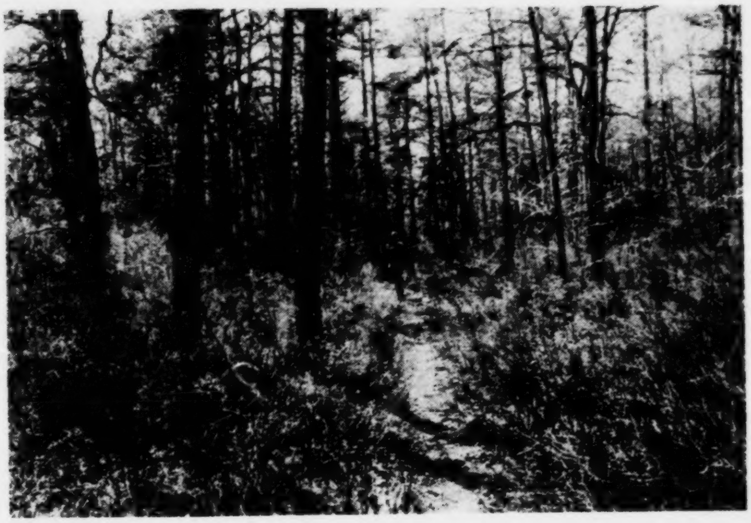


Figure 1a. Before right-of-way.[a]

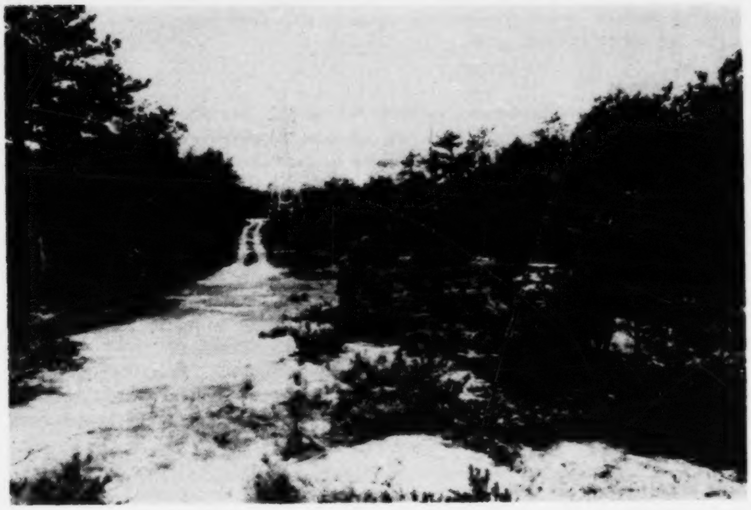


Figure 1b. At completion of right-of-way.[a]

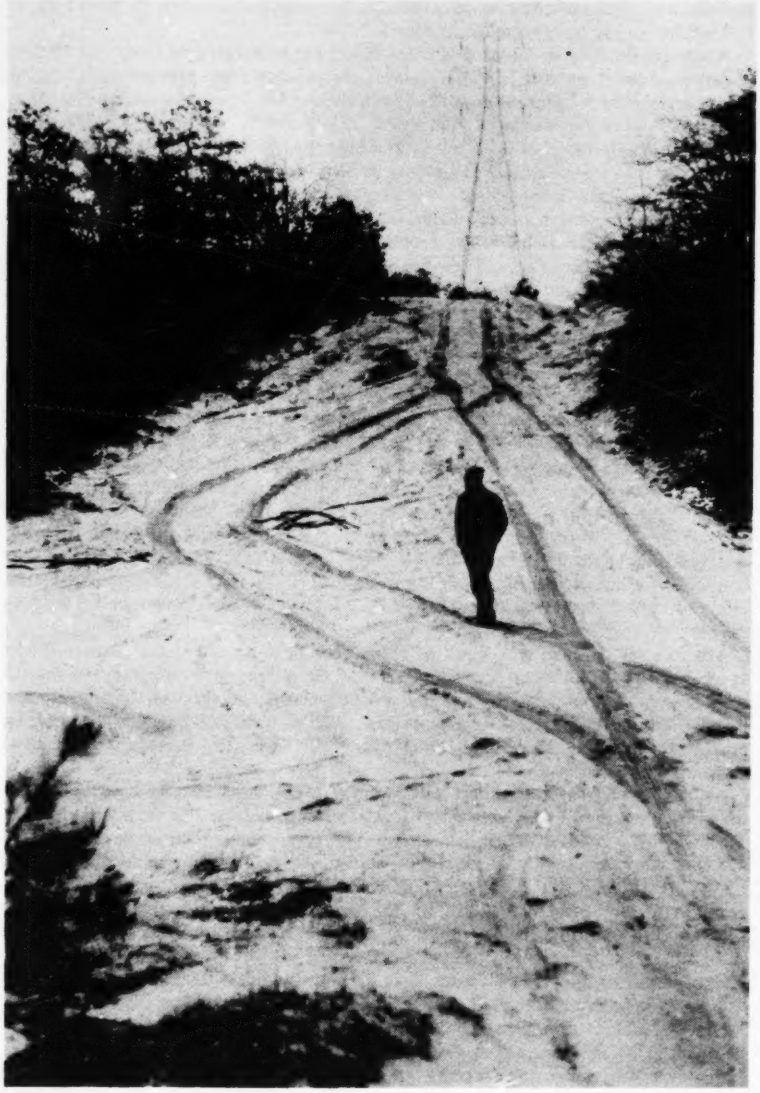


Figure 1c. Post right-of-way land degradation.[a]

victims are predominantly small cyprinids in nameless streams. It would be an interesting luxury to explore this mystery.

A special short-term threat to stream fauna are underground lines that require in-stream digging or flow control. Habitat degradation from pipeline construction was documented for a number of Michigan tributaries; impacts were limited to the crossings and a few hundred feet below this point.[13] The study also recorded beneficial effects when canopy removal resulted in thickening of bank vegetation. Environmental variables and unknowns confounded the interpretation and significance of other data in the report.

Perhaps the brightest spot in an assessment of streams and transmission lines, from the standpoint of research effort or ecologic understanding, is that we need not worry about large streams or rivers. Their health is a product of a large complex watershed in which transmission line impacts in this context all but vanish.

Wildlife Habitat Impacts

Most of what was learned came from non-ROW studies, such as those examining the wildlife effects of commercial clear-cutting, selective-timber harvesting, or controlled burning. Several investigations did focus on ROWs. Relevant studies of small mammals and songbirds in diverse localities and habitats had this in common: within a community some species are affected and some are not. Of those affected, some are benefited and some are harmed. Populations often fluctuate independently of treatment effects (e.g., clearing vs. control). Most measurements of these responses were in terms of short-term population or habitat-use changes. Few investigations ran for over eight years and sample sizes were often small. Nobody isolated transmission line effects on a tagged population to discover significant cause-and-effects events. Penetrating insight into these complex interactions is lacking, we only observe nature in the gross.

Most small mammal populations recover quickly from habitat perturbations; severe perturbations retard the process. A frequently cited songbird study[14] showed a 30 m ROW increased bird diversity, but a wide ROW (91 m) through forest decreased it. The latter did attract several grassland species. It is puzzling why the narrow corridor (12 m wide) lowered the index, for it too should have created a beneficial opening in the canopy.

Several investigators became curious about the barrier effects of ROW on mammal movements. For example, Idaho deer and elk were not visibly hindered in the fall of 1974;[15] and 25 *Blarina* and *Peromyscus* returned to their home range across a ROW when artificially displaced by experimenters.[16] Evidence from snowshoe hare,[17] deer,[18] and tree squirrel[19] research suggests more interesting results might come from an extensive study of the barrier and island-creating effects of transmission corridors in snow country. Likewise, published (and casual) observations suggest that increased human use of some corridors may significantly alter animal behavior and survival rates through hunting and vehicular disturbance.[20,21] Such impacts can be mitigated by clearing selectively and leaving slash as cover.[22]

Significant local changes result when basic habitat alterations occur (as they often do)—for example, when a grove of large mast and den trees are felled, or when severe soil compaction or erosion destroys friable soils needed by fossorial species. Studies continued to demonstrate edge-effects, mainly by species diversity indices. One study[23] took a detailed look at how edge and shrub-cover controls the movements of the rufous-sided towhee (*Pipilo erythrophthalmus*). It is not surprising that much recent research supports what one might logically expect based on past research.

Finally, in a major consultant-prepared report filed by a utility research organization with a state agency, we learn: *Site #1* "During the fall of 1975, two woodchucks were seen on the ROW . . . They ran to their burrows upon approach. . . Spring peeper activity was high off the ROW." *Site #2* ". . . A swallowtail butterfly was seen flying on the ROW at the time. Cottontail rabbit pellets were slightly abundant on xeric plot 3. . ." *Site #5* "One spring peeper was seen hopping in the woods on control plot 2 . . . One red eft was seen walking . . . in the swamp;" *Site #9* "Skunk redolence was noted on and off the ROW between structures 28 and 29; Two garter snakes were seen mating. . ." The significance of these observations was not discussed.

From all these bits and pieces, published and unpublished, we can be certain that in a healthy landscape, a well-managed ROW, which encourages a patchiness of mixed shrubs, low trees, and herbs, will have a positive and important effect on local wildlife communities whether in thick forest or open plain.

Herbicides

The accumulation of relevant herbicide literature has been immense, outweighing that of the other subject areas combined. Few ROW managers have the time, training or inclination to evaluate the technical output of chemists and toxicologists. We look trustingly at their published conclusions and summaries to see just how poisonous these valuable materials are to non-target organisms, or how persistent they are in soil or water. Clearly, the "objective Age of Science" is also a "subjective Age of Faith."

The wealth of articles on spraying technologies, and herbicide uses and results, are more comprehensible and interesting to managers. Because chemicals are controversial, those of us who believe herbicides are critical to management objectives must "justify" actions to adversaries and review panels. In this context, the following generalizations find abundant support in the scientific literature: chlorophenoxy herbicides and picloram can safely be used in Vegetation Management programs guided by the ecologic, sociologic and economic principles stated earlier in this paper. Research tells us that (1) these substances are of low toxicity to animals; (2) they biodegrade rapidly in the environment—except the picloram residues may last for one to two years; (3) they do not accumulate in food chains; and (4) that the contaminant TCDD or 2,3,7,8 tetrachlorodibenzo-p-dioxin occurs in miniscule amounts (<0.5 ppm) and is therefore non-hazardous under field conditions where 2,4,5-T is selectively and cautiously used.

Further, herbicides bind well to vegetation and soils and therefore are seldom detectable beyond a few feet from point of application. Greater movements are rare, but may happen when a heavy application is followed by heavy rain, in steep topography, with thin vegetation, or porous soil. Chemicals that get into lotic systems rapidly detoxify due to molecular breakdown and dilution. Academic findings and circumspection combine to suggest that special efforts should be made to minimize aquatic contamination. Concentrations of 1-5 ppm of silvex have been lethal to fish under laboratory conditions.[24] About the only way to get such a level in water is by direct application: no-spray buffer zones mitigate against this.

Unfortunately, most herbicide research is the product of those with vested interests in herbicide sales and use. Such research is therefore stigmatized. However, it is unlikely that studies by the most impartial scientific organization would satisfy certain anti-chemical activists if results go contrary to their emotional wants. Legitimate claims of herbicide damage (real and suspected) are traceable to carelessness, ignorance, apathy, unecologic management concepts, and war, all of which occur too frequently.[b]

Vegetation Management

Of concern here is research that goes beyond the level of individual species to examine *communities* of species. In other words, vegetation is, by definition, a complex of plant communities. Given this conceptual progression through Levels of Integration, our task of research-summarizing is simplified because few workers have studied vegetation as defined in this way. Academic "thorn-thickets" arise because observers perceive vegetation differently, are equipped with different methods, and proceed under different philosophies. The very nature of vegetation (and more so the biocommunity), the loosely-integrated aggregations of symbiotic species and species-associations, makes it a most difficult subject matter to comprehend. Perhaps managers are justified in snubbing the academics of this field. It is no secret that ROW brush can be well managed by simply killing single-stemmed target plants (trees) while leaving unharmed the desirable multi-stemmed ones (shrubs). It is so simple that one cynical vegetation scientist recommends hiring the mentally impaired to do the labor.

---

[b] The federal government ban on the selective use of 2,4,5-T on utility lines, no matter how *remote* the ROW, and how *low* the exposure hazard to pregnant women, was in my opinion the most "disillusioning failure" (with respect to rational, scientifically-based decision-making) of the decade.

ROW vegetation management research is predominantly an eastern phenomenon (more in the north than in the south). The leading activists are Frank Egler,[3] William Bramble,[25] William Niering,[26] and Kenneth Carvell.[27] Their work clearly distinguishes between (1) the effects of selective (stem-specific) removal, and (2) broadcast spraying of entire plant communities. This latter method, once heavily favored by industry for its expediency, often eliminates the desirable elements (shrubs and forbs) along with undesirable elements (trees). Often too, the trees grow back or reinvade faster than the low-growing populations, thereby creating a community of herbicide-resistant plants (e.g., ash, gray birch, pine, aspen, and *Andropogon*) that require cyclic respraying over the life of the line. Interestingly, our knowledge of such relationships comes mainly from extensive, general, *qualitative*, on-and-off ROW observations by these researchers; it is not supportable by the *quantitative* data in the meager literature. Is it, then, *un*scientific?

Sound vegetation management principles are now being applied by utility foresters in many states. Their efforts are often confounded by "practical problems:" inadequate budgets, intransigent engineers, and unskilled labor. There is a variety of techniques and materials available from which they must select to best fit the variable site conditions of a heterogeneous ROW landscape. The benefits and costs of these options in relationship to multi-goal management are only now beginning to be addressed. It will be two decades, at best, before the science and art can be anything near the ideals upon which we should insist.

Avian Conflicts

It seems that what the semi-arid western states lack in tall vegetation they make up for in large birds: hawks, eagles, ravens, vultures, and waterfowl. ROW biologists have responded accordingly. Enough observations on large-bird mortality associated with wires and electric poles have accumulated to stimulate scientific inquiry. Unfortunately, we can do no more than salute these efforts, and in passing cite two publications that admirably summarize the state of knowledge and the scope of concern.[28,29,c]

CONCLUSION

We have seen that transmission lines, so long ignored, were swept up in the ecology explosion of the 1970s. Penetrating into the field were methodologies, concepts and theories emanating from academia. Early in this article we recalled the effects of Clementsianism on ROW vegetation management and how this now largely discredited theory of relay succession was once regarded as ecological wisdom.

---

[c] *The Journal of Wildlife Management* did publish a major article[30] reporting that with respect to *waterfowl*, only 0.1 percent of non-hunting mortality (1930-1965) was due to collisions. Of these collisions, utility line strikes were predominant. However, many new lines have been built since 1965, and productive waterfowl habitat has shrunk.

Today there are new theories that scholars find infatuating. We might mention "MacArthurism"[d] and the sophisticated analytic methods associated with it. This erudition can now be found in the ROW literature. Admittedly the part it plays is yet small, but should it grow, competing for scarce funds for relevant ROW wildlife research, we might experience an episode not unlike the early years.

Of more concern is the contemporary passion to quantify, to amass and analyze data. Sampling methodologies now dominate ecology; the role they play in ROW research is major. This philosophy is a rub-off from hard sciences like chemistry and physics where facts, relationships and laws are well expressed by numbers, equations and probability statements. But can this elegance carry over into the complex living systems confronting field biologists? Are his integrated communities of interdependent-independent, dynamic evolving organisms at all analogous to the primitive non-biologic systems that the chemist and physicist deals with? And when one considers the time and effort required for a biologist to adequately sample a natural biotic system statistically, and then examines the project cost in light of meaningful ecologic knowledge gained, one's skepticism is fueled.

My concern grows when I see mathematical paradigms insensately applied to ROW vegetation or habitat. How well do these data and indices—this reductionism and excessive abstraction—represent complex plant communities? These communities are characterized by their ever changing structure, texture, color, succulence, form, variety, pattern, and fragrance which may cling, grasp, rip, tear, nurture, protect, and poison. And these communities also are productive, useful, intriguing, rewarding, troublesome, and sometimes even attractive in various ways and combinations.

If, in contrast to dangerously seductive numerology, future descriptions and interpretations can effectively utilize a "natural history approach," together with clarifying data, literary art, and pictorial records in the image-provoking manner of Botany's A. G. Tansley or Zoology's George Schaller, there is a chance for reshaping the skeptical and apathetic attitudes held by influential people who will determine the fate of biotic science in ROW management enterprises. Let historian-philosopher Will Durant advise us: "Art without science is poverty, but science without art is barbarism." Some rethinking is crucial for those of us who wish to earn our bread in field biology, for we must admit that such enthralling pursuits will surely become a niche of luxury as we enter the Age of Scarcity.

---

[d] A school of quantifying ecology traceable to the late theorist Robert MacArthur which holds as a working model that vertebrate species are nicely adapted to intermeshing niches formed through competition, giving rise to neatly structured communities.

REFERENCES

1. Wiltrout, T. R., and H. A. Holt. 1981. Use of 2,4,5-T for vegetation management on rights-of-way. p. 41-1. *In* Environmental concerns in rights-of-way management: Proceedings of Second Symposium. Electric Power Res. Inst. WS-78-141. Palo Alto, Calif.
2. Wecksler, A. N. 1973. Seven million acres of new ROW. Electric Light and Power. 51(16):19.
3. Egler, F. E., and S. R. Foote. 1975. The Plight of the Right-of-Way Domain: Victim of Vandalism. Futura Media Services. Mt. Kisco, N.Y. 2 Vols. 454 pp.
4. Clements, F. E. 1928. Plant Succession and Indicators. H. W. Wilson. New York, N.Y. 453 pp.
5. Dailey, N. S. 1978. Environmental aspects of transmission lines—a selected, annotated bibliography. Oak Ridge Nat. Lab. Oak Ridge, Tenn. 192 pp.

6. Asplundh Environmental Services. 1977. Environmental and economic aspects of contemporaneous electric transmission line right-of-way management techniques. 3 Vols. Empire State Electric Energy Research Corp. Guilderland, N.Y.
7. Aasheim, J. R. 1973. Assessing potential impacts of logging and road construction. Master's Thesis. Montana State Univ. Bozeman, Mont. 135 pp.
8. Megahan, W. F., and W. J. Kidd. 1972. Effects of logging and logging roads on erosion and deposition in steep terrain. J. Forestry. 70(3):136-141.
9. Swift, L. W., Jr., and J. B. Messer. 1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. J. Soil Water Conserv. 26:111-116.
10. Burns, J. W. 1972. Some effects of logging and associated road construction on Northern California streams. Trans. Amer. Fish. Soc. 101(1):1-17.
11. MacPhee, C., and F. J. Watts. 1976. Swimming performance of arctic grayling in highway culverts. Coll. Forestry, Wildl. and Range Sci. Bull. No. 13. Univ. Idaho. Moscow, Idaho. 41 pp.
12. Metsker, M. E. 1970. Fish versus culverts. Tech. Rept. ETR-7700-5. Engineering Tech. Info. Serv. USDA, Forest Service. Washington, D.C. 19 pp.
13. Crabtree, A. F., C. E. Bassett, and L. E. Fisher. 1978. The impacts of pipeline construction on stream and wetland environments. Mich. Public Serv. Comm. Lansing, Mich. 115 pp.
14. Anderson, S. H., K. Mann, and H. H. Shugart, Jr. 1977. The effect of transmission-line corridors on bird populations. Amer. Midl. Nat. 97(1):216-221.
15. Lee, J. M. 1977. Transmission lines and their effects on wildlife: a status report of research on the BPA system. Paper presented at Ann. Meeting of Oregon Chap. of The Wildl. Soc. Jan. 19-21, 1977.
16. Schreiber, R. K., and J. Graves. 1977. Powerline corridors as possible barriers to the movements of small mammals. Amer. Midl. Nat. 97(2):504-507.
17. Brock, R. H. 1975. Preliminary guidelines for managing snowshoe hare habitat in the Adirondacks. 1975 Northeast Fish and Wildl. Conf.: Abstracts. Conn. Dept. Environ. Protection. 40 pp.
18. Kelsall, J. R., and W. Prescott. 1971. Moose and deer behavior in snow. Rept. Series No. 15. Canadian Wildl. Serv. Ottawa, Canada. 25 pp.
19. Nixon, C. M., M. W. McClain, and R. W. Donohoe. 1980. Effects of clear-cutting on gray squirrels. J. Wildl. Manage. 44(2):403-412.
20. Lee, J. M., and D. B. Griffith. 1978. Transmission line audible noise and wildlife. pp. 105-168. *In* Effects of noise on wildlife. Academic Press. New York, N.Y.
21. Severinghaus, C. W., and B. F. Tullar. 1975. Wintering deer versus snowmobiles. The Conservationist (N.Y.). 29(6):31.
22. Davis, P. R. 1976. Response of vertebrate fauna to forestfire and clear-cutting in South Central Wyoming. Ph.D. Thesis. Univ. Wyoming. Laramie, Wyo. 105 pp.
23. Gates, E. J., and K. R. Dixon. 1981. Right-of-way utilization by forest and corridor-breeding bird populations. p. 66-1. *In* Environmental concerns in rights-of-way management: Proceedings of Second Symposium. Electric Power Res. Inst. WS-78-141. Palo Alto, Calif.
24. Wilbur, R. L., and E. W. Whitney. 1973. Toxicity of the herbicide Kuron (silvex) to bluegill eggs and fry. Trans. Amer. Fish. Soc. 102(3):630-633.
25. Bramble, W. C., and W. R. Byrnes. 1972. A long-term ecological study of game food and cover on a sprayed utility right-of-way. Res. Bull. No. 885. Purdue Univ. Agr. Exp. Sta. 19 pp.

26. Niering, W. A., and R. H. Goodwin. 1974. Creation of relatively stable shrublands with herbicides: arresting "succession" on rights-of-way and pastureland. Ecology. 55(4):784-795.
27. Carvell, K. 1978. Ecology of transmission lines. Electric Energy Res. Inst. Final Rept. No. EA491. Palo Alto, Calif.
28. Weir, R. D. 1976. Annotated bibliography of bird kills at manmade obstacles: a review of the state-of-the-art and solutions. Dept. of Fish and the Environ. Mgmt. Serv., Canadian Wildl. Serv. Ottawa, Canada. 85 pp.
29. Avery, M. L., ed. 1978. Impacts of transmission lines on birds in flight: Proc. of a Workshop. FWS/OBS-78/48. Office of Biological Services. Fish and Wildlife Service, USDI. Washington, D.C. 151 pp.
30. Stout, J., and G. Cornwell. 1976. Non-hunting mortality of fledged North American waterfowl. J. Wildl. Manage. 40(4):681-693.

RESTORATION OF DAMAGED ECOSYSTEMS

John Cairns, Jr.

WHY RESTORE DAMAGED ECOSYSTEMS?

Destroying or damaging a natural system is a reprehensible act. A badly damaged ecosystem is highly visible evidence of misplaced values. It proclaims not only ethical insensitivity of the society in which it occurs, but also poor management. After all, pollutants are merely misplaced resources. Nutrients added to lakes, rivers, and oceans are badly needed on our agricultural lands. Toxic heavy metals in waste streams of various manufacturing plants have commercial value.

Some of the worst environmental damage occurs near large cities or heavily settled areas. Most Americans are accustomed to getting in the family car and driving long distances for recreation. Since the cost of driving is now increasing dramatically, restoring areas closer to home and work makes sense. Benefits of such restorations reduce travel time to recreational areas and at the same time cut transportation costs and energy consumption.

Moreover, the impact on more remote fragile natural systems would be markedly reduced by restoring recreational areas in or near population centers. Finally there is the matter of civic pride. The British are justifiably proud and excited about the transformation of the tidal Thames from a virtually lifeless river emitting noxious fumes to a river which supports fish and various intensive recreational uses in one of the world's largest metropolitan areas. The restoration was done without bankrupting businesses. Indeed evidence indicates that not only has the river become more aesthetically pleasing but also that commercial value has improved far out of proportion to the cost of the cleanup.

In the 10 years since the United States Environmental Protection Agency (EPA) was formed, notable improvements in some American rivers (e.g., the Connecticut and the Ohio) and lakes (e.g., Washington and Erie) have been realized. Many strip mined lands have been converted from eyesores to systems furnishing amenities.[1,2] The EPA has fought to arrest further degradation of the environment and to reduce intrusion of deleterious materials into our air and water. While notable failures have occurred, such as the kepone situation in Virginia and the "valley of the drums," cautious optimism is still justified. Simply reducing the intrusion of deleterious materials into the environment will almost invariably trigger a natural recovery process. However, in the decade ahead, EPA should devote more attention to methods and practices which will enhance prospects for the recovery of damaged ecosystems, particularly in the case of disturbed lands.

Perhaps action on restoring damaged ecosystems has not been vigorous because people feel that such efforts may be terribly expensive, time consuming, and often fruitless. If the process were viewed as one of restoring certain amenities, and if

---

The Author: John Cairns, Jr., is University Distinguished Professor and Director, University Center for Environmental Studies, Virginia Polytechnic Institute and State University. He is President of the American Microscopical Society and a member of the U.S. Environmental Protection Agency Science Advisory Board, the Environmental Studies Board of the National Research Council, the Editorial Board of the American Resources Association and is an editor of the *Journal of Environmental Pathology and Toxicology*.

examples were available that such restoration could be done relatively quickly and at a cost that would not bankrupt society, more action might result. Ecologists have not covered themselves with glory in the area of recovery. They prefer to work mostly with pristine ecosystems rather than already damaged ones. As a consequence, there is a paucity of basic information that would make restoration efforts more efficient and expeditious. Nevertheless, evidence shows that present information and practices are adequate to do the job quite effectively. Consequently there is no scientific justification for postponing major restorative efforts.

EPA'S ROLE

Ecological systems provide society with values that can be categorized as goods, services, esoteric values, and long-range self-maintenance. Pursuant to maintaining the quality of the human environment, a keen interest in restoring disturbed or damaged ecosystems as well as those systems which may become disturbed through human activity, should be shown. Clearly, some of these systems must be returned to, and maintained in, their natural or near-natural state if our natural heritage is to be protected for future generations. Still other ecosystems will be restored to some relatively stable, but less than natural, state capable of providing society with goods and services.

Moreover, ecosystems restoration are best carried out with a full knowledge of the structural and functional characteristics of the conditions which are sought. Also, restoration should involve the most effective and efficient technology available. These technologies include effective manipulation of physical and chemical qualities of habitats, and effective species stocking and restoration programs. The emerging field of ecosystem restoration and enhancement has become a cornerstone of ecosystem management.

Those involved in this new technology must develop a detailed knowledge of the effects of each type of system perturbation. Rates of recovery and limits of tolerance beyond which perturbed systems cannot recover to desired states must be known and understood. All this information must be coupled with a knowledge of reversing conditions of disturbed systems.

In developing this new field, research should now be carried out in certain critical areas with a focus on specific ecosystems types. The sections that follow identify critical research needs.

Factors Important to the Restoration Process

Damage and subsequent recovery potential of stressed ecosystems depend upon three basic sets of factors: (a) type of system perturbed, (b) nature of the disturbance, and (c) mode of operation of the disturbing agent.

Representative Types of Ecosystems That May be Perturbed

Ecosystem types can be grouped conveniently into 10 categories: forests, grasslands, deserts, dry tundra, lakes, shallow wetlands (marshes, swamps, bogs, coastal wetlands, and wet tundra), streams and rivers, estuaries, continental shelves, artificial ecosystems (e.g., agricultural lands and reservoirs). The compositions and processes of these ecosystem types vary in relation to climate, geographic location and altitude.

An estuary in Oregon may differ in species composition and certain basic functional characteristics from one in Louisiana or Massachusetts. Consideration should be given to this heterogeneity when tolerance and responses to perturbations are studied. Furthermore, a conscientious attempt should be made to understand the restoration needs of each system type in terms of its unique and shared qualities.

Major Types of Ecosystem Perturbation

The major types of ecosystem perturbations include nutrient enrichment, acidification, addition of toxic substances, nutrient depletion, surface mining, habitat modification (such as stream flow alteration), destruction of native species (such as impingement and entrainment), and introduction of alien species. Understanding how each of these perturbation types affects each ecosystem type is important. The nature and severity of the effect will also depend on the intensity, duration, and seasonal occurrence of the perturbation.

Mode of Perturbation Activity

The characteristic mode of response of an ecosystem to a given type of perturbation depends upon whether the primary effect of disturbance is upon the system's structural components or upon its functional processes. Some effects are stimulatory; others are inhibitory; and yet others affect the system's structural characteristics. These effects are illustrated in the Figure 1 ((from Cairns et al.[3]). The relationship of the major types of perturbations to the modes of activity is shown in Figure 2.

Recent Phases in Perception of Problem

The academic community's or society's perception of its relationship to the environment presumably will go through a third and fourth phase beyond the two already experienced. The first was an awareness phase which most people in the United States associate with the "earth days" of the late sixties and seventies. Although Aldo Leopold, Rachael Carson, and many others were fully aware of assaults on the environment at a much earlier time, society as a whole paid little attention to their warnings at first. Nevertheless, these early warnings ultimately resulted in a general awareness of environmental problems. The second phase was one in which biological effects of chlorinated hydrocarbons and other materials released into the environment were documented and quantified.

The third phase is now beginning. This phase involves the development of prediction models for estimating the probability of harm that will result from various courses of action (e.g., use of new chemical) before that action is taken. In short, phase three involves the development of a predictive capability.

A logical next step is the development of a regional (e.g., drainage basin, etc.) management plan incorporating both predictive and reactive methods (e.g., quality control methods) to maintain desirable ecosystem quality and to restore that quality when it has been degraded.[4] Additionally, society undoubtedly will wish to restore certain damaged ecosystems to original condition or to conditions more acceptable

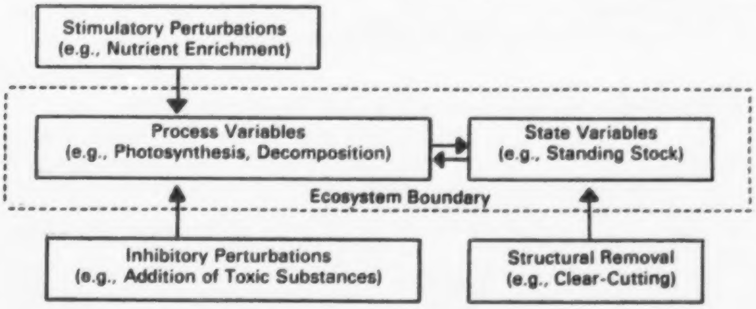


Figure 1. Modes of action of perturbants on ecosystems.

Modes of Action Perturbations	Stimulatory	Inhibitory	Structural
Nutrient Enrichment	X		
Acidification		X	
Addition of Toxic Substances		X	
Nutrient Depletion		X	
Surface Mining		X	X
Habitat Modification			X
Habitat Destruction			X
Destruction of Native Species			X
Introduction of Alien Species			X

Figure 2. Relation of perturbation type with modes of action.

to society's needs. This chapter will focus only tangentially on the awareness problems and the documentation of damage. One of the chief developmental needs should be the production of prediction models and regional management protocols. Therefore, this chapter will address these two important areas.

ENVIRONMENTAL IMPACT STATEMENTS

As a result of the passage of the National Environmental Policy Act (NEPA) in 1972, environmental impact statements have emerged as very significant documents in the attempt to reduce deleterious environmental effects resulting from societal activities. These documents are intended to establish the condition of ecosystems. Both governmental and non-governmental institutions have allocated very substantial resources for both preparation and evaluation of often lengthy impact statements. The value of this rather monumental effort should be examined in terms of both the original objectives and the ability to furnish a baseline against which future conditions can be compared.

NEPA originally was hailed by many environmentalists as a major step in the effort to improve environmental protection. But after a few years, considerable concern over the effectiveness of this effort surfaced in the community of ecologists. A number of these concerns were explicitly addressed in the symposium sponsored by the Council for Environmental Quality at the Ecological Society of America's annual meeting with the American Institute of Biological Sciences in New Orleans, Louisiana in 1976.[5] Presumably, the symposium proceedings will someday appear and be available for examination.

Among the concerns expressed was that a significant fraction of time has been spent merely reading environmental impact statements[6,7] (not to mention that financial and professional resources were expended in gathering the data). These environmental impact statements have not served the purpose intended, and there is disagreement about whether they can ever do so. Major improvements are needed in the quality of impact statements if they are to serve the purpose intended.[8,9] Most of the environmental impact statements consist primarily of long lists of species either collected from the site and subsequently identified, or reported to be in the general area on the basis of literature often many years old. Rarely are there any insights into biological or ecosystem processes or predictions of the consequences of the proposed course of action upon these processes. Even in cases where the impact involved alterations in diversity, this could not have been confirmed with mere species lists. Additionally, density, biomass, recruitment rates, and the like were rarely provided with species lists. In almost all cases, changes of considerable ecological concern in the output of the system, such as productivity and nutrient losses, received little or no attention. Rarely was the stability in structure or function of the system discussed in even the most superficial manner.

Another major flaw in the preparation of impact statements is the lack of care in the identification and selection of the key processes that are essential to maintaining the integrity of the system. Without a scientifically justifiable selection of such processes, gathering of data and experimental design will be inadequate. Over the decade, selection of inappropriate parameters has resulted in the failure to predict and/or document important environmental alterations when they occur and, equally important, has diverted scarce resources from assignments that might be more productive.

A key lesson to be learned from NEPA failures is that inventorying species alone will neither enable one to accurately predict the environmental and ecological consequences of a proposed course of action nor document changes in biological integrity (particularly once damage has occurred). Such prediction and documentation require a solid knowledge of the processes involved.

Thus, before going very far into rehabilitation and restoration of ecosystems, identification of ecological processes critical to this purpose is essential. Although theoretical ecologists have provided much information about ecological processes, they have not been very helpful in showing how such information can be used to make predictions of impact or to forecast the process of recovery. It is a *sine qua non* that the need for creative and knowledgable professional ecologists is no less at the analysis and interpretation stage as it is in the design and data collection stage. Although ecologists plead for more use of ecological concepts and theory in assessing and predicting societal impacts on the environment, most of the decisions are based on single species toxicity tests. The problem is that theoretical ecologists have not taken the time to help in this important undertaking. Dayton[10] states: "Another symptom of a serious problem is that after at least 70 years, during which ecology has been considered a respectable scientific discipline, we are usually unable to offer substantial positive contributions to the many societal problems confronting us."

DOCUMENTING ECOSYSTEM CONDITION

The River Thames offers an excellent example of the long abuse of a river and the partial restoration of certain desirable qualities. At Isleworth, salmon were plentiful until the early 19th century. In 1848, a report stated, "salmon have been driven from the river by the gas-works and stream navigation."[11] Gameson and Wheeler[12] report that the Thames started to decline as a fishery about 150 years ago. By the 1950s, despite occasional partial recovery, the only fish able to survive in the most polluted reaches were eels.

Gameson and Wheeler[12] state in their introductory section that the deliberate restoration of the Thames estuary was solely for the benefit of part of the external ecosystem, namely man. The need for restoration arose mainly from the offensive smell of hydrogen-sulfide emanating from the estuary during the summer months some 25-30 years ago. This restoration brought in its wake a remarkable recovery of the biotic component, and fish returned to the estuary in ever increasing numbers.

In the tidal portion of the River Thames, pollution has been a matter of concern for hundreds of years. The pollution received much attention, of course, because of the location of one of the world's largest cities, London, on its banks. As early as 1620, the bishop of London expressed in a sermon the hope that "the cleaning of the river . . . will follow in good time." A century and a half later, Tobias Smollett wrote in *Humphrey Clinker*: "If I would drink water, I must quaff the maukish contents of an open aqueduct exposed to all manner of defilement; or swallow that which comes from the River Thames, impregnated with all the filth of London and Westminster—human excrement is the least offensive part of the concrete, which is composed of all the drugs, minerals, and poisons used in mechanics and manufacture, enriched with the putrefying carcasses of beast and man; and mixed with the scouring of all the wash-tubs, kennels, and common sewers, within the bills of mortality."

The Thames was still a good fishing river in the 18th century; large numbers of salmon could still be caught. For exmaple, 130 were sent to market on a single day in 1766. As far as is known, the last salmon was caught in 1833, and by 1850 all commercial fishing had ceased.

Nothing was done to the river despite the fact that the condition of the Thames in central London had become so vile in the mid-19th century that sheets soaked in disinfectant were hung in the houses of Parliament in an attempt to counteract the stench. This culminated in 1858 with a smell at Westminister so overpowering that its control became of great personal interest to the members of Parliament. In that year, work was started on the construction of intercepting sewers to carry the sewage from central London to Barking on the north and to Crossness on the south side of the estuary.

As recently as 1957-58, Wheeler[13] concluded that from the region of Gravesend upstream for some 68 km there was no evidence of fish life (with the single exception of eels, which were found in the upper reaches of this area). This was a period in which there were extremely low dissolved oxygen concentrations and, at times, anaerobic conditions in the river.

During 1964 and 1965, reports of fish impingement (caught on intake pipe screens) on the cooling water intake streams at the newly commissioned steam electric power station at West Turrock indicated that some fish were returning to the river. As a consequence, the Central Electricity Generating Board made arrangements to collect fish caught on screens at the power stations in the London area. Between 1967 and December 1973, a total of 68 species of fish were captured at power generating stations on the intake screens. Of these, 18 were freshwater fish, and 43 were of marine origin. Doxat[11] reports over 90 species of fish have been found in the Thames tideway area in recent years. A serious effort is now being considered to restore the salmon run to the Thames.[14]

The Thames furnishes some very useful background information to consider in the restoration of damaged ecosystems. Even though England was scientifically one of the most enlightened places in the world during the period of the industrial revolution, little substantive data exist on the condition of the Thames before degradation began, except for records for some of the commercially valuable species, and some subjective evaluations of the quality of the water.

Little seems to be known about the lower organisms present before degradation began or even the higher organisms considered then to have no particular economic value. Since ecology is a relatively new science which really began to flourish only in the last part of this century, measurements of various rate processes (such as carbon fixation, recruitment rates for various species, etc.) are totally unknown. In short, most of the measurements considered important by contemporary ecologists are unavailable for both terrestrial and aquatic ecosystems in which the degradation process began with industrialization. Who knows much about the ecology of the Ohio River before the locks and dams were installed?

POLICY OPTIONS FOR MANAGEMENT OF NATURAL ECOSYSTEMS

Figure 3 from Magnuson et al.[15] provides a beautiful schematic for the various options available when one is trying to determine what to do with a damaged ecosystem. *Restoration* as used in this chapter and in the Magnuson et al.[15] chapter means returning in a direct route toward its initial condition or state. This would include both desirable and undesirable characteristics of the original condition. An example of an undesirable condition in this context might be thickly overhanging vegetation on a small stream which might prevent use by canoeists. Further *degradation* would continue to take the system toward a new state in a "direction" opposite to its original condition. Pragmatic *rehabilitation* would include restoration of original characteristics considered particularly desirable as well as some new desirable characteristics which were not originally present. *Enhancement* would involve restoration to a more socially acceptable condition than the present one, but with no reference to or use of the original condition as a model. For example, strip mined land in Kansas that was originally covered by prairie grassland might be converted to a small lake or pond. This would be ecologically quite distinct from its original state but a properly constructed lake or pond would certainly be considered by most citizens more desirable than abandoned strip mined land and, therefore, the conversion could be termed enhancement.

The resolution of the problem seems to require:

1. Identification of those ecosystems that have been displaced from their original conditions.
2. Determination of whether displacement is still occurring.
3. When continuing degradation has been observed, arresting it so that a steady state is reached.

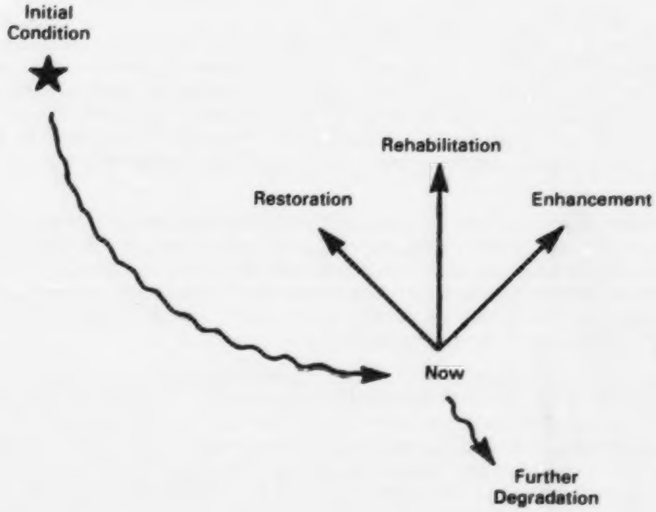


Figure 3. Diagram to illustrate the meaning of several policy options for management of natural ecosystems.

4. Determination of whether restoration, rehabilitation, enhancement, or maintaining a steady state condition at the present level is most desirable.
5. Determination of desired qualities of the ecosystem (which is a social-political decision, not a scientific one).
6. Determination of the cost and time necessary to reach a series of alternative quality conditions. This would include an estimation of whether or not return to an original condition is ecologically feasible and, if so, whether it could be accomplished within an acceptable time framework.
7. Implementation of the management plan to restore the system to the desired conditions.
8. Simultaneous placement of a biological monitoring program to track the direction and rate of change toward the desired quality conditions.
9. Once the desired quality conditions are attained, a biological monitoring system should be maintained as part of an overall quality control program. This should include provision for making hazard evaluations of all activities that could result in displacement of the system from its desired condition.

Until these questions are resolved in a justifiable, scientific manner, ecosystems will quite likely be damaged and consequently require restoration. Equally important in these troubled financial times are industrial concerns about spending money for waste treatment that will have no demonstrable biological benefits. Until a closer correlation exists between the degree of waste treatment required and the biological benefits thereby derived, strong industrial and municipal resistance to implementing federal and state standards will persist.

PREVENTION OF ECOLOGICAL DISPLACEMENT

Enhancement, rehabilitation, and recovery are all expensive, time-consuming, and sometimes rather chancy operations.[16,17,18,19,20,21,22,23] Therefore, preventative measures that will reduce the need for such activities are absolutely essential. This will enable those charged with environmental protection and restoration to focus scarce resources on fewer cases. Even then, the areas requiring rehabilitation at a minimum will be so numerous that priorities will have to be set. The main burden of the restoration in most cases will fall on local agencies.

Species lost from a damaged system must be replaced either naturally or by management practices. The more healthy areas one has as a source for natural invasion, the more likely the recovery process will occur naturally rather than through management. Thus the more ecosystems which can be protected and kept in their present condition, the less costly will be the restoration of those already damaged.

A means of protecting ecosystems from damage due to industrial chemicals would be useful since their production and distribution is controlled. The Toxic Substance Control Act (TSCA) requires that evidence be provided concerning the hazard these chemicals pose to human health and the environment during their extraction, transportation, manufacture, use, and disposal.[24] Unfortunately, practically all of the evidence available upon which to make decisions on hazards of toxic chemicals consists of single species laboratory tests.[a]

Ecosystems are presumed to be protected if the following conditions are fulfilled: (1) an array of species representing different trophic levels are tested, (2) the response of the most sensitive species determines the critical concentration, and (3) the critical concentration is multiplied by an application factor (a factor which estimates sensitivities not measured in the critical concentration).

---

[a] Paragraph 11 of the Settlement Agreement in Natural Resources Defense Council, et al. v. Train, 8 ERC 2120 (D.D.C. 1976) required EPA to publish water quality criteria for 65 specified pollutants by June 30, 1978. A revised Settlement Agreement required publication (for public comment) of 29 criteria documents by March 1, 1979, and the remaining 36 documents by July 1, 1979. The proposed criteria were published in the *Federal Register* on March 15, July 25, and October 1, 1979. Almost all of the information on toxicity for all 65 chemicals was based on single species tests.

There are a number of drawbacks to this assumption. It is by no means certain that the most sensitive of the relatively small array of species exposed in the "real world" will be represented among the tested in the laboratory (see Mount and Gillett, this Monograph). In fact, the most sensitive species quite likely cannot be cultured in the laboratory. Furthermore single species tests cannot, by definition, include such factors as predation, competition, and other relationships which are so important in the functioning of communities and ecosystems. Neither can these tests determine effects on nutrient and energy transfer and other relationships equally vital to the functioning of communities and ecosystems. Finally, single species laboratory tests cannot accurately mimic the environmental partitioning, the transformations, and other processes and changes that characterize a chemical's movement fate in a natural ecosystem.

Until these important factors are considered, an accurate estimate of hazard from the use of a particular chemical is not likely.[25]

INAPPROPRIATE INTERVENTION

Many ecosystems go through periodic ecological upheavals as a consequence of fires, floods, and other natural events. Often the fairly regular frequency of these events causes ecosystems to depend upon them. Vogl[26,27] and others have termed these "perturbation-dependent ecosystems." The differences between perturbation-independent systems with regard to disturbance is illustrated in Figure 4 from Vogl.[27] Sometimes when the perturbation is thought to be caused by disease or insect pests, ecologists are tempted to intervene and "restore" the system to its "original" condition.

A situation in which such a temptation was successfully avoided is described by Mueller-Dombois.[28] It involved the 'ōhi'a dieback phenomenon in the Hawaiian rainforest. This was first reported by Mueller-Dombois and Krajina[29] about a decade ago on the island of Hawaii. The decline was described as a "severe epidemic," and a prediction was made that the native rainforest would be eliminated in 15-25 years if the rate of damage had continued. This prediction implied that the native rainforest had been stricken by a newly introduced disease. But intensive disease research was begun in 1972 by the U.S. Forest Service and simultaneously by Mueller-Dombois with the assumption that the dieback might be a recurring natural phenomenon in primary succession. Mueller-Dombois[28] concluded that the dieback was not due to a newly introduced insect/pest or disease-causing organism but rather to climatic instability. Fortunately in this case massive intervention did not occur.

However, this particular case history and a number of others involving floods and fires indicate that intervention was inappropriate and would probably actually endanger the survival of certain species in perturbation-dependent ecosystems. EPA and other regulatory agencies would be well advised to take note of such case histories and be certain that intervention to restore an ecosystem to its original condition is appropriate and will arrest degradation resulting from man-induced deterioration rather than natural cyclic phenomena. Such long-term studies as those found in the Woods Hole Conference,[30] Loucks,[31] Botkin,[32] Toyryla,[33] Bormann and Likens,[34] and Edmondson[35] will provide the type of information needed to determine when intervention is required.

ECOLOGICAL REFUGES

The prospects for natural recolonization of damaged ecosystems and for rapid return to original conditions (or to a condition which included many of the original qualities) will be enhanced if invading organisms can reach damaged areas from nearby ecological refuges. These refuges not only protect the basic genetic endow-

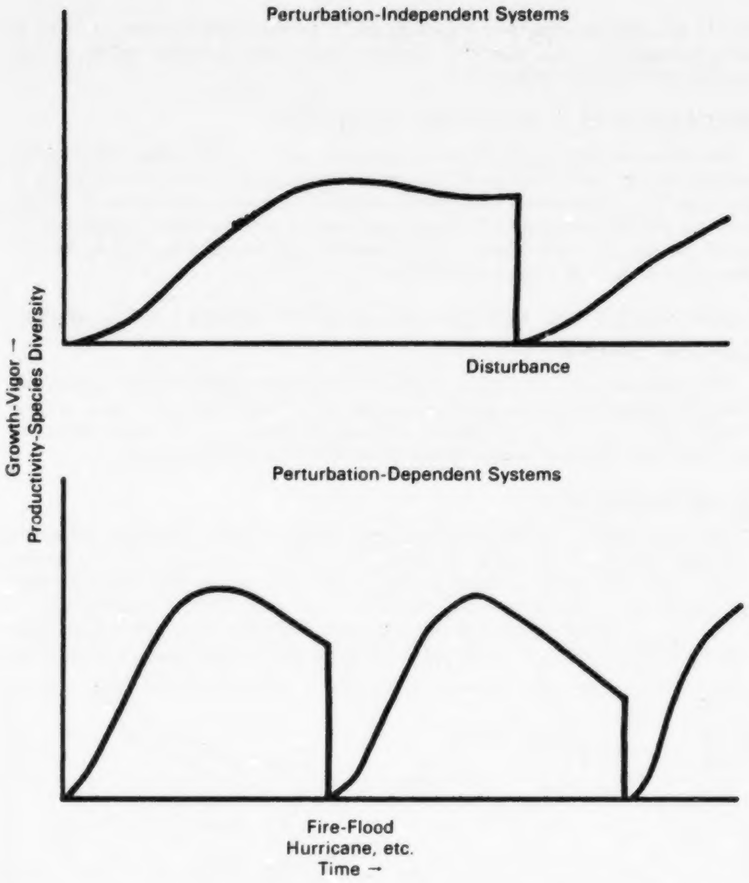


Figure 4. Disturbances in general ecosystems create vegetational setbacks and complete recovery is slow, whereas disturbances in perturbation-dependent ecosystems usually stimulate pulses of growth which rapidly decline unless disturbed again.

ment of natural systems, but they also provide the genetic and species resources necessary to restore damaged ecosystems. Refuges distant from damaged ecosystems but with suitable reinvading species could still be extremely helpful if human assistance were given to the invasion process.

Little attention has been given to the preservation of natural systems that would be suitable for this purpose. Since ecosystems continue to be damaged at an alarming rate, the development of refugia to aid the rehabilitation process should have a high priority.

ECOSYSTEM HYPERSENSITIVITY

At a symposium held in 1976, Cairns and Dickson[36] speculated that ecosystems might lose their resiliency (ability to "snap back" after successive displacements) following repeated exposure. This is termed *hypersensitivity* by Rapport et al.[37] It is at least possible that both hypersensitivity and acquired resistance occur. Neither is well documented at the system level. However, the section to follow may have some bearing on the sensitivity question.

DIFFERENTIAL ECOSYSTEM SENSITIVITY

There is some preliminary evidence that communities in the active colonization process may be more sensitive to toxicants than mature communities.[38] If this is generally true, communities recovering from one perturbation may be more vulnerable to a second shock than they would otherwise be. The regulatory implication of this is that recovering ecosystems need even more protection than healthy ones if they are to recover as rapidly as possible.

DOES IMPROVED WASTE TREATMENT RESULT IN ECOSYSTEM RECOVERY

The important question "Will improved waste treatment produce significant biological improvements in damaged ecosystems?" has not inspired many studies in which evidence on direct correlation between the two events has been obtained. However, such evidence is not difficult to obtain. Two examples follow.

Shenandoah River

Beginning in 1972, 10 surveys of benthic invertebrates and 9 static fish bioassays have been carried out to assess the impact of AVTEX Fibers, Inc. effluent on the lower South Fork of the Shenandoah River.[39] AVTEX (previously FMC Corporation) produces rayon and polyester fibers in Front Royal, Virginia. Benthic invertebrates were collected at four stations, one above and three below plant discharges (Figure 5). River surveys in 1972 and 1973 indicated a severe impact on the benthic

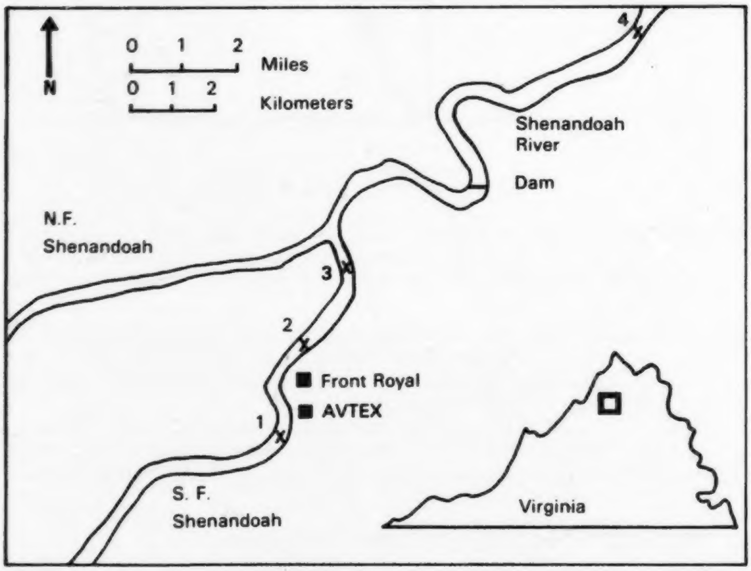


Figure 5. Location of the sampling stations on the South Fork and the main stem of the Shenandoah River, Warren County, Virginia.

community on the right (facing downstream) side of the river below the plant (the waste did not mix laterally very well). Diversity (d) was low (0-2.42) and the numbers of taxa and organisms were reduced. A fish bioassay carried out in 1973 indicated the wastewater discharge to be acutely toxic at a concentration of 34.5% (mixed with 65.5% river water).

In early 1974, FMC Corporation built an activated sludge treatment plant to reduce BOD_5 and improve the neutralization and chemical precipitation (zinc hydroxide and liquid-solid separation) facilities that had been in use since 1948. In 1975, d values had improved (1.19-3.39), and there were more taxa and organisms (Table 1). Wastewater (100%) was acutely toxic to fish only once after improvements had been made. The major changes in the wastewater discharge were a 70% reduction in BOD_5 and a 60% reduction in the amount of zinc entering the river (Table 2).

South River

The South River in Waynesboro, Virginia, receives wastes from both industrial and municipal discharges (Figure 6 and Table 3). Following a baseline study,[40] du Pont instituted further improvement in wastewater treatment (Table 4). This resulted in a definite improvement in the river biota (Figures 7,8,9).

Both these studies indicate that the river has improved, though still receiving wastewater discharges.

FUTURE RESEARCH NEEDS

The lack of measured evidence leads to a very important question: since so little evidence is presently available (except in terms of species inventories) about most of our ecosystems, what types of evidence should be gathered now in order to be adequately informed should ecosystems be damaged in the future and society wishes to restore them? Clearly, species inventories alone are not adequate if only because the successional process ensures that such inventories will become outdated. This will occur rapidly in some systems but ultimately in all, even the most stable. Perhaps one might want to characterize a community in terms of the functions the various species carry out, such as detritus processing, photosynthesis, predation, etc. If so, is the mere listing of biomass responsible for each of the component activities sufficient, or are various rate processes required as well? One would intuitively think both are necessary.

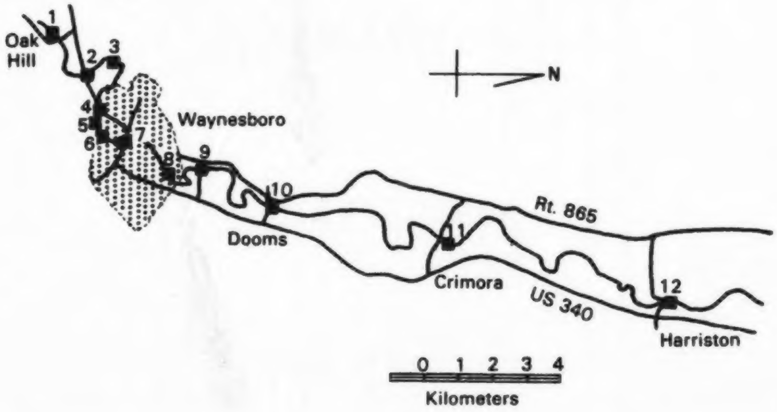


Figure 6. Sampling stations on the South River, Virginia for the 1978 biological survey.

Table 1. **Mean number of organisms for unstressed and stressed areas for the 10 surveys from 1972 and 1977**

		Station 2		Station 3		
Year	Station 1	Unstressed (substations 1-4)	Stressed (substations 5-6)*	Unstressed (substations 1-2)	Stressed (substations 3-6)*	Sta.4
1972	213	471	27	313	100	257
1973	403	517	121	172	30	935
1974	753	526	842	344	106	404
1974	823	1081	458	558	187	4492
1975	996	1323	1176	2128	334	1077
1975	1073	1424	350	897	194	580
1976	434	1712	424	1085	646	1428
1976	2494	1486	642	1025	758	6689
1977	381	803	633	323	123	446
1977	1284	1432	293	401	271	8866
Grand mean	916	1078	497	725	275	2518

*These substations where designated as stressed as a result of a Duncan's Multiple Range Test on $\bar{d}$ values and number of taxa comparing all substations at Stations 2 and 3 ($P < 0.10$).

Table 2. **Mean annual flow, zinc, BOD_5, for AVTEX's effluent from 1972 to 1977**

	Flow	Zinc		BOD_5
Year	(m³/sec)	(mg/l)	(kg/day)	(mg/l)
1972	0.36	8.3	262	78.5
1973	0.39	6.3	216	137.0
1974	0.49	3.3	141	36.9
1975	0.36	3.0	95	12.9
1976	0.40	3.1	108	18.7
1977	0.42	2.1	75	33.0

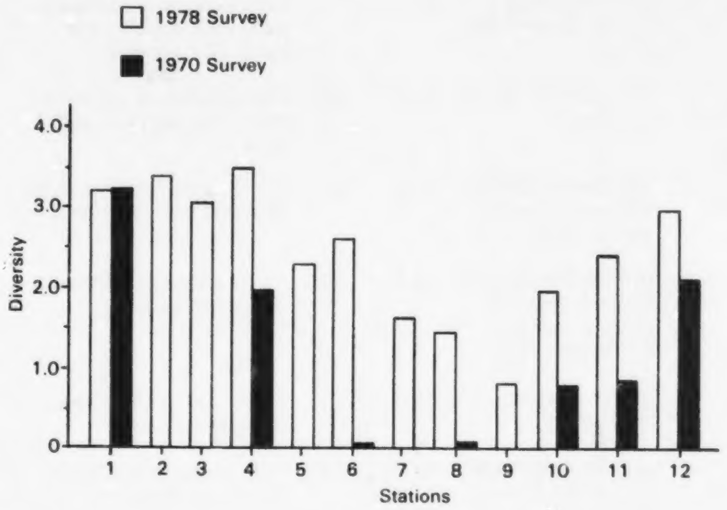


Figure 7. Comparison of macroinvertebrate community diversity ($\bar{d}$) for the 1970 and 1978 South River surveys.

What sort of system properties might be useful in establishing baseline conditions? An illustrative list follows: (1) productivity, (2) nutrient cycling or spiraling, (3) biomass, (4) diversity, (5) decomposition or detritus processing, (6) properties contributing to stability, such as resiliency, elasticity, and resistance to stress, and (7) spatial relationships of various types.

Additionally, a number of general concepts which are applicable to nearly all ecosystems should be kept in mind when gathering data. Some of the biological parameters that might be useful are mortality, reproductive success, growth rate, genetic variability, nutrient flow, and partition coefficients. Some of the ways in which alteration from desired conditions might be documented include alterations in: population size, age distribution, species interactions, and spatial distribution. Deleterious effects might also be recognized by life history table changes, alterations in population turnover rates, or in alterations of functional parameters such as: turnover rates in nutrients, rates at which storage of nutrients and other materials in sinks become altered, and so on.

Table 3. Description and location of the 12 sampling sites for the 1978 biological survey

Station #	Location	Mean depth (cm)	Mean velocity (cm/sec)	Substrate
1	OAK HILL, 50 m above RT 650 bridge	43.4	104	Even distribution of large and moderate size rocks, pebbles and sand
2	APPLE ACRES, 100 m below RT 664 bridge	36	95	70% large rocks; 30% pebbles and sand
3	GOLF COURSE, 1.3 km below RT 664 bridge	35.5	112	Even percent of moderate size rocks, pebbles and sand; 20% bedrock
4	DUPONT PROPERTY above all E.	20.2	58.5	Even percent of moderate size rocks, pebbles, and sand
5	DUPONT PROPERTY below Dupont's E. above Thiokol's E.	34.5	68	Small limestone rocks over bedrock; very little sand
6	DUPONT PROPERTY below Thiokol's E. above Crompton-Shenandoah's E.	24.5	70.5	~70% pebbles and sand; 30% small rocks
7	At CITY BRIDGE, RT 250	18.2	74	~70% pebbles and sand; 30% small rocks
8	NORTH CITY PARK, 200 m above 2nd St. bridge	17.5	82.5	~80% pebbles and sand; 20% small rocks
9	HOPEMAN PKWY, 150 m below bridge	18.7	78	30% large rocks; 70% small rocks, pebbles, and sand
10	DOOMS, 100 m above RT 611 bridge	43.3	110	40% moderate size rocks; 60% even distribution among small rocks, pebbles, and sand
11	CRIMORA, 300 m above RT 640 bridge	36	110	Even distribution among small rocks, pebbles, sand
12	HARRISTON, 100 m above RT 778 bridge	43.2	96	60% large rocks; few small rocks; ~30% pebbles and sand;

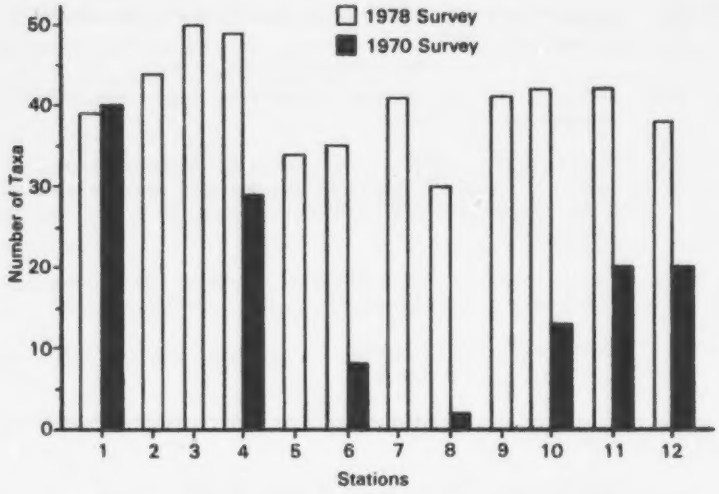


Figure 8. A comparison of the number of macroinvertebrate taxa collected for the 1970 and 1978 South River surveys.

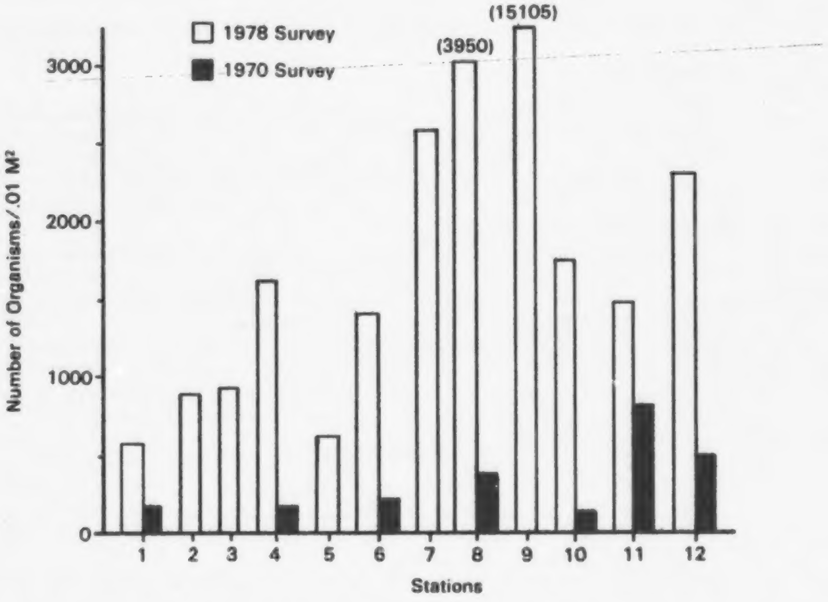


Figure 9. Macroinvertebrate density comparison for the 1970 and 1978 South River surveys.

Table 4. Improvements in Dupont's waste treatment system since 1970

Date	Waste treatment improvements
1970	Increased aeration capacity - added one aeration tank, one air blower, and one clarifier
1972	Improved spill control - interceptor sewer collected several sewers that discharged directly into the river into one which is monitored continuously and diverted to waste treatment should a spill occur
1976	Extended aeration begun followed by filtration - added 10 million gallon aerated tank followed by multi-media filtration
	Increased aeration capacity - added one aeration tank and one clarifier (total of 5 each)
	Added hydrogen peroxide system to reduce floating solids from clarifiers
	Ended thermal discharges from Outfalls 003 and 004
1977	Increased aeration capacity to provide additional oxygen transfer capacity for one-step nitrification - added one aeration tank and two blowers
	Improved aeration capacity in blend tanks - added Kenics mixers to each tank and 3 blowers

SUMMARY

The decade of the seventies produced compelling evidence that damaged ecosystems can be improved. A substantial body of literature for both aquatic(e.g. 41) and terrestrial(e.g. 42,43) ecosystems is available to help develop good management practices and avoid bad ones. Underlying ecological theory has not been neglected.(e.g. 37,44,45) Some of the problems in implementing water quality goals mentioned by Westman[46] late in the decade have since been addressed as have those involving control of environmental impact discussed by Westman and Gifford[47] earlier in the decade. However, most of the important problems identified by these authors remain unresolved. Fragmentation of authority[48] for ecosystem management remains as much of a problem at the end of the decade as it was at the outset. Guidelines for working environmental values into public decisions are available[49] but not generally used. The decade just completed produced a solid scientific foundation for restoring damaged ecosystems although much research is still needed. However, the damage rate still far exceeds the restoration rate.

REFERENCES

1. Samuel, D. E., J. R. Stauffer, C. H. Hocutt, and W. T. Mason, Jr. 1978. Surface mining and fish/wildlife needs in the Eastern United States. FWS/OBS-78/81. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 386 pp.
2. Samuel, D. E., J. R. Stauffer, C. H. Hocutt, and W. T. Mason, Jr. 1979. Addendum to surface mining and fish/wildlife needs in the Eastern United States. FWS/OBS-78/81A. Office of Biological Services, Fish and Wildlife Service, USDI. Washington, D.C. 125 pp.

3. Cairns, J., Jr., R. Darnell, R. Hutnik, H. Kibbe, L. McCormick, and K. Perey. 1979. Ecosystem. pp. 46-56 *In* Cooperative agreement for the evaluation of current environmental research and establishment of priorities. S. P. Mayers, Jr., Project Director. Program in Health Planning and Administration, Pennsylvania State University and Office of Research and Development, U.S. Environmental Protection Agency. Washington, D.C.
4. Cairns, J., Jr. In press. Predicting and reactive systems for aquatic ecosystem quality control. *In* Scientific basis of water resources management. Geophysics Research Board, National Research Council. Washington, D.C.
5. Reisa, J. J., ed. In press. Biological evaluation of environmental impact. Council on Environmental Quality, Washington, D.C.
6. Fairfax, S. K. 1978. A disaster in the environmental movement. Science. 199:743-748.
7. Ward, D. V. 1978. Biological environmental impact studies: theory and methods. Academic Press. New York, N.Y. 157 pp.
8. Schindler, D. W. 1976. The impact statement boondoggle. Science. 192:509.
9. Goodmen, D. 1975. The theory of diversity-stability relationships in ecology. Q. Rev. Biol. 50:237-266.
10. Dayton, P. K. 1979. Ecology: a science and a religion. pp. 3-18 *In* Ecological processes in coastal and marine systems. R. J. Livingston, ed. Plenum Press. New York, N.Y.
11. Doxat, J. 1977. The living Thames: the restoration of a great tidal river. Hutchinson Benham. London, England. 96 pp.
12. Gameson, A. L. H., and A. Wheeler. 1977. Restoration and recovery of the Thames estuary. pp. 72-101 *In* Recovery and restoration of damaged ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, eds. University of Virginia Press. Charlottesville, Va. 531 pp.
13. Wheeler, A. 1958. The fishes of the London area. London Nat. 80-101.
14. Paxton, D. 1978. Fisheries and recreation on freshwater rivers and reservoirs. pp. 5.1-5.12 *In* Thames Potomac Seminar. Thames Water Authority. London, England
15. Magnuson, J., Jr., H. A. Regier, W. J. Christie, and W. C. Sonzogni. 1980. To rehabilitate and restore Great Lakes ecosystems. pp. 95-112 *In* The recovery process in damaged ecosystems. J. Cairns, Jr., ed. Ann Arbor Science Publishers, Ann Arbor, Mich.
16. Barton, J. R., and P. V. Winger. 1973. Model stream studies of rehabilitation structures. Center for Health and Environmental Studies, Brigham Young University. Provo, Utah 89 pp.
17. Zarger, T. G., J. B. Maddox, L. B. Starnes, and W. M. Seawell. 1979. Ecological survey recovery after reclamation of toxic spoils left by coal surface mining. EPA-600/7-79-209. U.S. Environmental Protection Agency. Washington, D.C. 77 pp.
18. Barton, J. R., and P. V. Winger. 1974. Stream rehabilitation concepts. Engineering Research, College of Engineering and Technology, Brigham Young University. Provo, Utah 44 pp.
19. Cairns, J., Jr., K. L. Dickson, and E. E. Herricks, eds. 1977. Recovery and restoration of damaged ecosystems. University Press of Virginia. Charlottesville, Va. 531 pp.
20. Holdgate, M. W., and M. J. Woodman, eds. 1976. The breakdown and restoration of ecosystems. Plenum Press. London, England. 496 pp.
21. Lockerety, W. 1978. The lesson of the dust bowl. Amer. Sci. 66(5):560-569.
22. Echelberger, W. F., Jr. 1979. Cedar Lake restoration feasibility study. Environmental Systems Application Center, Indiana University. Bloomington, Ind. 248 pp.

23. Dunst, R. C., S. M. Born, P. D. Uttormark, S. A. Smith, S. A. Nichols, J. O. Peterson, D. R. Knauer, S. L. Serns, D. R. Winter, and T. L. Wirth. 1974. Survey of lake rehabilitation techniques and experiences. Tech. Bull. No. 75, Department of Natural Resources. Madira, Wisc. 179 pp.
24. Federal Register. 1974. Vol. 39, October 8.
25. Cairns, J., Jr. 1980. Estimating hazard. BioScience. 30(2):101-107.
26. Vogl, R. J. 1977. Fire: a destructive menace or a natural process? pp. 261-289 *In* Recovery and restoration of damaged ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, eds. University Press of Virginia, Charlottesville, Va. 531 pp.
27. Vogl, R. J. 1980. The ecological factors that produce perturbation-dependent ecosystems. pp. 63-94 *In* The recovery process in damaged ecosystems. J. Cairns, Jr., ed. Ann Arbor Science Publishers. Ann Arbor, Mich.
28. Mueller-Dombois, D. 1980. The 'ōhi'a dieback phenomenon in the Hawaiian rainforest. pp. 153-161 *In* The recovery process in damaged ecosystems. J. Cairns, Jr., ed. Ann Arbor Science Publishers. Ann Arbor, Mich.
29. Mueller-Dombois, D., and V. J. Krajina. 1968. Comparison of east-flank vegetation on Mauna Loa and Mauna Kea, Hawaii. Recent Adv. Trop. Ecol. 2:508-520.
30. Woods Hole Conference. 1977. Long-term ecological measurements. National Technical Information Service. Springfield, Va. 26 pp.
31. Loucks, O. L, 1979. Long-term ecological research: concept statement and measurement needs. Proc. of the Instructional Ecology Workshop. Indianapolis, Ind. 27 pp.
32. Botkin, D. B. 1978. A pilot program for long-term observation and study of ecosystems in the United States: report of a second conference on long-term ecological measurements. Woods Hole, Mass. 44 pp.
33. Toyryla P. 1979. Publication of the Hubbard Brook ecosystem study. Cornell University. Ithaca, N.Y. 34 pp.
34. Bormann, F. H., and G. E. Likens. 1979. Catastrophic disturbance and the steady state in northern hardwood forests. Amer. Sci. 67:660-669.
35. Edmondson, W. T. 1979. Lake Washington and the predictability of limnological events. Arch. Hydrobiol. 13:234-241.
36. Cairns, J., Jr., and K. L. Dickson. In press. Risk analysis for aquatic ecosystems. *In* Biological evaluation of environmental impact. J. Reisa, ed. Council on Environmental Quality, Washington, D.C.
37. Rapport, D. J., and J. E. Turner. 1977. Economic models in ecology. Science. 195:367-373.
38. Cairns, J., Jr., K. M. Hart, and M. S. Henebry. 1980. The effects of a sublethal dose of copper sulfate on the colonization rate of freshwater protozoan communities. Amer. Midl. Nat. 104(1):93-101.
39. Seagle, H. H., Jr., A. C. Hendricks, and J. Cairns, Jr. 1980. Does improved waste treatment have demonstrable biological benefits? Environ. Manage. 4(1):49-56.
40. Cairns, J., Jr., and K. L. Dickson, eds. 1972. An ecosystematic study of the South River, Virginia. Water Resources Research Center Bull. No. 54. Virginia Polytechnic Institute and State University. Blacksburg, Va. 104 pp.
41. Regier, H. A., and W. L. Hartman. 1973. Lake Erie's fish community: 150 years of cultural stresses. Science. 180:248-1255.
42. Boyle, J. R. 1975. Nutrients in relation of intensive culture of forest crops. Iowa State J. Res. 49(3):297-303.
43. Boyle, J. R. 1976. A system for evaluating potential impacts on whole-tree harvesting on site quality. TAPPI. 59(7):79-81.
44. Odum, E. P., J. T. Finn, and E. H. Franz. 1979. Perturbation theory and the subsidy-stress gradient. BioScience. 29(6):349-352.

45. Bazelon, D. L. 1979. Risk and responsibility. Science. 205:277-280.
46. Westman, W. E. 1977. Problems in implementing U.S. water quality goals. Amer. Sci. 65(2):197-203.
47. Westman, W. E., and R. M. Gifford. 1973. Environmental impact: controlling the overall level. Science. 181:819-825.
48. Platt, R. Hl., and G. M. McMullen. 1979. Fragmentation of public authority over floodplains: The Charles River response. Water Resources Research Center Publ. No. 101. University of Massachusetts. Amherst, Mass. 112 pp.
49. Andrews, R. N. L., and M. J. Waits. 1978. Environmental values in public decisions: a research agenda. School of Natural Resources, University of Michigan. Ann Arbor, Mich. 90 pp.

FISH AND WILDLIFE RESEARCH NEEDS AS RELATED TO ENVIRONMENTAL ASSESSMENT

Michael D. Zagata

INTRODUCTION

Fish and wildlife research relating to environmental assessment work (both basic and applied) must be increased to minimize the potential for detrimental impacts associated with man's activities, and to provide adequate information so that decision-makers can make ecologically sound decisions.[1] This synthesis of a statement issued by the Chairman of the President's Council on Environmental Quality reflects the feelings of professional wildlife (including fish) researchers, managers, and policy and decision-makers. Their feelings reflect those of the general public, which has been the driving force in the passage of numerous laws aimed at bettering the environment.[2] Gottschalk[3] summed up the situation:

> Our problem of sustaining the production of fish and wildlife in future years will grow at something approaching a geometric rate. It is not a simple question of learning more about our living resources, though with the broadening consciousness of the ecological web, that in itself constitutes a tremendous challenge. We must learn how to "make more with less"—to make fewer acres of land or water sustain the numbers and varieties of fish wildlife essential for the food and recreational needs of future generations.

LEGISLATIVE MANDATES FOR ENVIRONMENTAL ASSESSMENT

National Environmental Policy Act

In response to the public's concern for maintenance and enhancement of environmental quality, Congress and the Administration enacted numerous laws during the late 1960s and the 1970s. Fish and wildlife resources, whether by design or accident, benefited greatly from this environmental legislation. The National Environmental Policy Act (NEPA) of 1969, while limited to major Federal actions, provided a mechanism, the environmental impact statement, for assessing the potential impacts of some man-induced perturbations on a given system in advance of the action.

In fact, NEPA is the cornerstone of environmental legislation and has served as the umbrella mandate for many of the acts discussed later in this paper. It requires all Federal agencies to consider environmental values along with economic or developmental considerations and encourages the interdisciplinary approach to addressing environmental impacts. NEPA's main purposes are: "to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the

---

The Author: Dr. Zagata currently is employed by Tenneco, Inc. as Manager of Ecological Sciences, Department of Industrial Ecology, V.P.O. Box 2511, Houston, TX 77001. This paper was written while Dr. Zagata served on the Board of Agricultural and Renewable Resources, National Academy of Sciences, Washington, D.C.

environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources of the Nation, ..."

NEPA, however, created problems for those attempting in good faith to comply with it and for those charged with administering it because the data did not, in many situations, exist to permit a valid analysis or the selection of a "less damaging" alternative action.[4,5,6] A mere listing of species known to inhabit an area was not enough. Data were needed regarding habitat requirements, species interactions and basic life history so that ecologically sound trade-offs could be made and scientists could predict the environmental impact of a given action both on-site and on a cumulative basis. In recognition of the need for more comprehensive information, the U.S. Fish and Wildlife Service, Division of Ecological Services, lists two elements that should be common to all environmental impact assessment methods:[7]

1. The environmental impact assessment should have the capability to quantify the extent and status of various natural resource components and their susceptibility to irreparable damage or loss. All physical, biological, economic, and social parameters relevant to the change expected from a proposed action should be addressed.
2. The environmental impact assessment should objectively predict the quantitative and qualitative short- and long-term changes in physical, chemical and biological features associated with alternative ways of achieving the proposed objective. The "goodness" or "badness" of each alternative is determined by the decision-maker(s) and is not made a part of the assessment.

As the environmental assessment has matured, the existing shortcomings have been recognized and attempts are being made to remedy them via research. That research is what this monograph is all about. In attempting to outline these research needs, we will examine: (1) the legislative mandates that have created information needs for the resource managers; (2) the efforts of agencies to comply with those mandates by undertaking massive efforts to inventory and classify resources data; (3) the analysis of the data from an ecological perspective (i.e., quantification of the relationship between species and their habitats so that predictions can be made); and (4) the treatment of the data in an assessment process where man's values are incorporated into the decision-making process.

Inventory and Assessment Legislation

During the 1970s, Congress became increasingly concerned with the condition of our nation's renewable resources and passed legislation requiring an inventory and assessment of those resources.[8] Such legislation included the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), the Federal Land Policy and Management Act of 1976 (FLPMA), the National Forest Management Act of 1976 (NFMA), and the Soil and Water Resources Conservation Act of 1977 (RCA).

The above four acts, respectively, affected the U.S. Forest Service (FS), Bureau of Land Management (BLM), Soil Conservation Service (SCS), and the Fish and Wildlife Service (FWS). The FS and SCS had established inventory methodologies which were functional rather than ecological systems and thus needed to be broadened in scope. The FWS had a long history of inventory work with regard to wetlands, but needed to develop a broader approach. The BLM's inventory methodology has come about largely as a result of FLPMA. Each agency lacked the inventory methodologies to fully meet its mandate. Moreover, their responsibilities overlapped in some areas. Therefore, the FS, BLM, SCS, FWS, and the U.S. Geological Survey (GS) have joined in a five-way interagency agreement to cooperate in the development of classifications and inventories of major renewable resources, including fish and wildlife.

The Endangered Species Act of 1973 (ESA) generated other problems for the scientists. Even the taxonomists found their data to be subject to question. "What is a species" was a question often raised in Congress during hearings to amend the ESA. Scientists concerned with traditional management now found themselves struggling to designate critical habitat and to employ techniques, based upon the life history of species, to improve the status of the species in question.

RESEARCH NEEDS AND DIRECTION

Cringan et al.[9] recently summarized the current status of fish and wildlife research. This 1979 study ascribes these attributes to fish and wildlife research: (1) it is difficult to discriminate between basic and applied research, as they are ill-defined portions of a single continuum; (2) it is increasingly multidisciplinary in structure; and (3) wildlife scientists in Canada and the U.S. are major contributors to, and beneficiaries of, global research in wildlife.

The issue of whether basic or applied research should be given funding priority rages on, but, as pointed out by Cringan et al., this need not be an issue at all. According to the National Science Board, the distinction between basic and applied research is a matter of purpose, not of subsequent use:[10]

1. Basic research: "Research which has the purpose of acquiring scientific knowledge of nature phenomena, where the primary aim is fuller understanding of the subject of study, rather than specific application of the resulting knowledge."
2. Applied research: "Research which may have a similar purpose, but the prime aim is the potential application of the acquired knowledge."

It is obvious that the full range of options within the continuum from basic to applied research is applicable to the problems associated with the development and application of inventory methodology and other skills necessary to make accurate ecological predictions.

Cringan et al.'s reference to the multidisciplinary structure of fish and wildlife research is a prerequisite to the solution of increasingly complex fish and wildlife issues. In 1968, the Journal of Wildlife Management had an average of 1.8 authors for the 88 papers and 41 shorter articles; in 1978, the average was 2.2 authors for 72 papers and 75 articles.[9] These data indicate an increase in multidisciplinary research on wildlife.

At a time when complex relationships need to be examined in depth over a long-time interval in order to expand our ability to make valid inventories and predictions, our research effort seems directed toward short-term studies to solve immediate crises. The five major sectors in the U.S. which conduct wildlife research: private industry, Federal agencies, universities, state agencies and nonprofit organizations, have established a trend toward short-term (less than five years) applied research. If we accept Cringan's distinction between basic and applied research (if the aim is fuller understanding, the research is basic; if application, the research is applied),[9] then the myriad legislative mandates and an effort to balance the Federal budget will continue to drive the research efforts toward short-term, applied research. This could, in the long run, be detrimental to the generation of new knowledge and thus to management efforts because, as shown by Bok,[11] there is a vital link between basic science and its application. According to the National Science Board[10] and Smith and Karlesky,[12] there is evidence of deterioration of science in this country and an insufficiency in basic research is a critical problem.

Resource Classification and Inventory

Nearly all of the authors in this monograph have discussed a particular classification system, inventory methodology or assessment and planning framework (Klimstra, Russell, Bailey, Cushwa, Johnston). The October 1978 issue of the Journal of Forestry was devoted to a discussion of land classification and inventory.[13] There was renewed need for this attention to an area that had been undergoing constant refinement because the existing classification and inventory systems were largely functional, i.e., inventories for timber, soil. The need today is for ecological systems that portray the data in a manner that allows the decision-maker to look at interactions and trade-offs between and among functional systems. This need has been fostered by numerous acts that require an inventory and assessment of all the resources within the scope of the agency's mandate. Among these laws are the RCA, RPA, NFMA, FLPMA, the Coastal Zone Management Act of 1972 (CZMA), and the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Earlier examples include the Sikes Act, Fish and Wildlife Act of 1956, and the Fish and Wildlife Coordination Act of 1934.

Unfortunately, the basic research and subsequent applications were not in place to implement the mandated programs. The flurry of activity that followed the legislative mandates resulted in a fragmented effort by each agency to comply, a situation reflected by the myriad acronyms for classification and inventory methodologies that appear throughout this monograph. In fact, it is a generally accepted premise that no one system is likely to prove suitable for all purposes for all agencies.[14] However, a conscious effort must be made to assure that the various methodologies generate data that are compatible. Initially, it appeared that jurisdictional battles would hamper the development of a compatible classification and inventory system. Indeed, there were large discrepancies in the acreages of timber and rangeland types reported in the 1980 assessments conducted under the RPA and the RCA. To their credit, the FS, BLM, SCS, FWS and the USGS have joined in a cooperative effort to help assure the compatibility of their data.

Research should be aimed at the development and implementation of classification schemes and inventory techniques that are both applicable and suitable to a variety of species and habitats. Such research is a first step in providing the decision-makers and the public with the information necessary to make ecologically sound decisions with regard to the management of fish and wildlife and the habitats that support them. We need to know, at the local, regional and national levels, what is there, how much of it exists, and where it is located. To do this, a standardized system generating data which can be integrated into a central data base must be in place. Then we can begin to make scientifically sound trade-offs involving the relationships between species and between species and other resources.

METHODS OF APPROACH

It is apparent that the traditional, functional system type of inventory will not provide the kind of information required by decision-makers to comply with the law. Greater emphasis will likely be placed on: 1. research on the life history of a species; 2. interactions between and among species; 3. interactions between species and abiotic environmental factors; 4. habitat requirements; 5. revised economic methodologies for cost benefit analyses; and 6. sociological-psychological considerations.

The FWS has discussed four ways to assess impacts on fish and wildlife resources framed around four indicators of public interest: species-populations, biological (ecological) integrity, environmental values, and habitat. Examination of impacts on species-populations would follow the autecological approach, and be concerned with the species-population in question. Those assessments involving the ecological approach would be concerned with an integrated ecosystem or synecological approach.

According to NEPA, equal consideration must be given to economic and environmental values associated with a project. Such a treatment would be classed under the "environmental values" approach. The habitat approach would consider the impacts on that component of the ecosystem necessary to support the organism(s) in question.[15] The methodologies presented within this monograph fall into one or more of the four categories.

From a research-needs standpoint, it is desirable to cite the potential assessment criteria listed by the FWS:[7]

1. The assessment method should document and display data in a manner which allows decision-makers to compare present conditions with future options and alternatives.
2. The assessment method should have predictive capabilities amenable to documentation of changes in both quantity and quality of fish and wildlife resources over time. It is not enough to document existing resources; the assessment method must be able to project changes in the resource base which occur naturally or as the result of implementation of a proposed action by man.
3. The assessment method must be practical to implement. Data availability, time, and monetary constraints must be considered in the practical application of any method.
4. The assessment method must be sensitive enough to identify differing types and magnitudes of impacts ranging from enhancement to no impact, some loss, or to total loss of the resource.
5. The assessment method should generate data with biological validity, but in units readily understood by both the public and decision-makers. These data should be amenable to integration with data from other disciplines, such as socioeconomic analyses.
6. The assessment method should be complete and self-contained yet capable of being improved through the incorporation of new knowledge and techniques as the state-of-the-art advances.

The important point is that the approach should be suited to the kind of need, i.e., the analysis to be done rather than the data determines the approach used for the assessment. Depending upon the complexity of the problem and the magnitude of the impacts, the assessment may be performed via an analysis of energy flow, population estimation, habitat quality, habitat potential or a combination thereof.[7,16]

From a standpoint of the decision-maker and the long-term status of the resources, the use of habitat potential, or carrying capacity, offers the following advantages: numbers of species and individuals may change for unpredictable reasons, but habitat potential remains relatively unchanged and the time scale for predictions can come close to matching the time span over which impacts will occur. However, measures of carrying capacity are difficult to obtain and should only be used where they meet the need.

As a result of the need to integrate information and to make predictions based upon "limited" information, the science of modeling has developed. Like any panacea, modeling has its flaws. We have all heard the old adage, "garbage in = garbage out." However, the better the data, the better the results.[17] Thus, one can look at the development of a model as a tool for identifying gaps in our knowledge. As the modeling technique becomes more refined, it is apparent that inventories alone will not provide the necessary data to refine the model.

Through the use of models to integrate, where necessary, this broad array of information, scientists will begin to feel more comfortable extrapolating beyond their data to predict the likely impact of a given perturbation on a species specific or community-wide basis. According to Sanderson et al.:[18] "The basic goal in wildlife research is an information base on animals and their habitats that will allow prediction of effects of changes in animal-habitat relationships."

In line with this goal, they list the following six objectives for wildlife, including fishery, research:

1. Knowledge of the biology of species and ecosystems to accumulate a long-term data base on wildlife habitats and communities on a national scale.
2. Development of deductive formulation of specific research needs based on an understanding of biological processes, and utilizing long-term data on wildlife habitats and communities.

3. The capability to prescribe land use designs for various wildlife communities based on predictive capabilities.
4. Predictive capabilities for dealing with effects on wildlife and habitats.
5. Understanding the minimum survival requirements of wildlife species, populations, and communities at all stages of their life cycles.
6. New methods, and improvement of existing methods for rapid transfer of information in a form readily understood and accepted by users.

The need for administrators to predict the impact of a given action or series of actions is exemplified by the consultation requirements of Section 7 of ESA, and by NEPA. They must know in advance if any action "is likely to have" an impact on a species or its critical habitat. Thus a clear need exists for predictive capability. It is also clear that our research effort must be expanded in the areas we have listed in order to meet the six objectives stated by Sanderson et al.[8]

In addition, NEPA and the Fish and Wildlife Conservation Act of 1980 require a greater knowledge of wildlife, both game and nongame species. Thus, one would expect that research on the nongame species which addresses Sanderson et al.'s six objectives would increase and prove productive.

The Fish and Wildlife Coordination Act of 1934 provides for the mitigation of losses in fish and wildlife habitat caused by Federal water-development projects. How does one determine what was lost and what it will require to mitigate that loss? Much research has been sponsored and conducted by the FWS to develop techniques to answer these questions. The Habitat Evaluation Procedure (HEP) used by the FWS has promise,[19] but other systems are and will likely continue to be developed. This is another fertile area for research. For example, Adaptive Environmental Assessment (AEA), discussed by Holling in this monograph, is one approach that is being used.[20]

Another positive feature of modeling is that it encourages the interdisciplinary approach to research. In the process, scientists including biologists, ecologists, physiologists, biometricians, physicists, chemists, economists, sociologists, psychologists, agronomists, foresters, range scientists, administrators, and planners are drawn together.

Consideration of Values and Attitudes

Little is known about the attitudes of the various publics toward wildlife. However, the need for more information in this area is attracting the attention of the Federal agencies and researchers. Kellert,[21] for example, is currently conducting a study of "Public Attitudes Toward Critical Wildlife and Natural Habitat Issues." Hopefully his work and that of Hendee[22] and Trefethen[23] will provide wildlife and fishery professionals with some insight toward wildlife. It is becoming increasingly apparent that if wildlife is to compete successfully for public support in the context of resource allocation issues, wildlife professionals must be able to influence public attitudes with factual, understandable information.

Research efforts in this area present, in fact mandate, an opportunity for interdisciplinary research. Few, if any, fish and wildlife professionals are trained in sociology and psychology. The reverse is true for sociologists and psychologists.

Economic Approaches

Thus far we have discussed various approaches, including species-populations, communities, habitat, and environmental values, to "valuate" fish and wildlife for environmental assessment purposes. Another approach is to consider the economic "value" of fish and wildlife. If fish and wildlife, traditionally viewed as non-commodity items, are going to compete successfully in a commodity-oriented society, then the research effort devoted to developing new economic methodologies and valuation procedures must be expanded.[24] Environmental legislation, like the FWCA, has created an opportunity, indeed a critical need, for a method of determining the economic "value" of fish and wildlife. Fish and wildlife, in terms of traditional economic theory, are given no value. Historically, wildlife values have been estimated by: gross expenditures, expenditures for transportation and other variable costs, willingness to pay, income forgone,[25] and annual replacement values.[18] According to Sanderson et al. we need to understand why these approaches led to substantially different estimates, and we should identify the most appropriate approaches for various uses.[18]

Without improved methodology to generate values that the public and decision-maker can understand and appreciate, fish and wildlife will finish last in the allocation process.

In addition to determining the value of fish and wildlife to society, we need to identify and document the value of various kinds of habitat to society. If their value is recognized and is high enough to compete, they will be maintained and their associated fish and wildlife will benefit.

Wetlands, for example, help society by having a beneficial influence on flood control, water quality, fisheries, groundwater, wildlife and aesthetics. Larson (this monograph) noted that:

> "As long as wetlands were viewed as having only value for wildlife, the prospects of maintaining an adequate network of wetland wildlife habitat were dim. Research of the last decade has identified health, safety and welfare values that stem from basic ecological functions of wetlands and these issues have attracted interest in and support for public management of wetlands to maintain these functions."

Research efforts need to be directed at the value of other critical wildlife habitat to society. For example, what benefits accrue to society from sound floodplain management, from protecting riparian habitats, from measures to reduce soil erosion, and from perpetuating genetic variety by maintaining representative ecosystems?

FUNDING NEEDS

Monies for fish and wildlife research have increased significantly during the past ten years.[9] However, so has the task at hand. Congress, as a reflection of society in general, has placed increasingly greater demands for information on agencies while keeping a tight rein on the purse strings and personnel ceilings. Thus, much of the research is crisis oriented, done on a short-term basis, and increasingly farmed out to consultants.

In order to enable the agencies to meet their mandates, Congress and the Administration must recognize their need for an increase in research funds and personnel ceilings. Further, the role of the universities in research must be strengthened, especially in the area of basic research. The National Fish and Wildlife Resources Research Council, a voluntary group of concerned scientists, is working with the Congress and the universities to explore ways to bolster their role in fish and wildlife research.

SUMMARY

According to White,[26] "To deal effectively with the whole range of environmental problems that are evident or emerging would call, ideally, for perfect knowledge of the natural systems to be affected." However, the resource manager and decision-maker is faced with a dilemma. According to Thomas:[27]

> "The knowledge necessary to make a perfect analysis of the impacts of potential courses of. . .management action on wildlife habitat does not exist. It probably never will, but more knowledge is available than has yet been brought to bear on the subject. To be useful, that knowledge must be organized so it makes sense. . ."

Realizing that, in a world of imperfect knowledge, decisions will, of necessity, be made regarding the allocation of resources and the trade-offs between species and other resources, Thomas[27] goes on to say:

> "Perhaps the greatest challenge that faces professionals engaged in. . . research and management is the organization of knowledge and insights into forms that can be readily applied. To say we don't know enough is to take refuge behind a half-truth and ignore the fact that decisions will be made regardless of the amount of information available. . .it is far better to examine available knowledge, combine it with expert opinion on how the system operates, and make predictions about the consequences of alternative management actions."

This is not to suggest, however, that research in the area of fish and wildlife impact assessment is complete or that it should cease. Quite the opposite is true. As our ability to analyze and synthesize has increased, the gaps in the knowledge necessary to expand our understanding and make predictions about impacts have become obvious. The basic research regarding the life history of an organism and its relationship to its habitat and ecosystem is lacking for most species, especially the nongame species. However, now that those gaps have been recognized, efforts are being made to fill them.

The classification and inventory methodology is in a state of flux and will likely remain that way for some time. Congress has imposed inventory and assessment mandates on numerous agencies with myriad responsibilities. It is doubtful that any one system will meet all its needs. But a concerted effort must be made to insure that the data generated in one system is compatible with that generated by other systems. A centralized data base is a likely outcome of the joint effort of the agencies to work together in meeting their mandates.

Research must also be expanded in the area of fish and wildlife valuation. This monograph has treated numerous approaches to "valuate" fish and wildlife. In general, they are by: species-population, community, environmental values, habitat, and economics. Greater effort must be devoted to developing "valuation" methodologies that will allow fish and wildlife to better compete in resources-allocation decisions.

It is generally accepted that the United States has the world's best funded and largest number of fish and wildlife scientists. Their work is unexcelled, yet according to Cringan et al.[9] they fall short of their potential for the following reasons: 1. imbalance in ratio of applied to basic research; 2. overemphasis of short-term, at the expense of long-term studies; 3. sub-optimal levels of multidisciplinary efforts; 4. overemphasis of commercially important species, as compared to nongame species; and 5. emphasis upon single species, rather than on communities and ecosystems.

Overall, the Congress has provided a tremendous opportunity for those professionals working with fish and wildlife resources. Their mandate is clear—develop an improved data base and "valuation" methodologies and inventory information to enable fish and wildlife resources to compete in the resources allocation process. Their challenge will be met.

REFERENCES

1. Speth, G. 1979. Preface. *In* Trans. Forty-Fourth N. Amer. Wildl. and Nat. Resour. Conf. March 24-28, 1979. Toronto, Ontario, Canada. Wildlife Management Institute. Washington, D.C.
2. Udall, S. L. 1963. *The Quiet Crisis.* Holt Rinehart, and Winston. New York, N.Y. 266 pp.
3. Gottschalk, J. S. 1979. Concluding remarks. p. 83. *In* Trans. Forty-Fourth N. Amer. Wildl. and Nat. Resour. Conf. March 24-28, 1979. Toronto, Ontario, Canada. Wildlife Management Institute. Washington, D.C.
4. Schindler, D. W. 1976. The impact statement boondoggle. Science. 192:509.
5. Watt, K. F. 1977. Why won't anyone believe us? Simulation. 28(1):1-3
6. Ward, D. V. 1978. *Biological Environmental Impact Studies: Theory and Methods.* Academic Press. New York, N.Y. 157 pp.

7. U.S. Fish and Wildlife Service. 1980. Habitat as a basis for environmental assessment (ESM 101). Division of Ecological Services. Washington, D.C.
8. Bean, M. J. 1978. Federal wildlife law. pp. 279-289. *In* Wildlife in America. Council on Environmental Quality. H. P. Brokaw, ed. Washington, D.C. 532 pp.
9. Cringan, A. T., D. H. Arner, R. J. Rosel, J. W. Thomas, and R. L. Walker. 1979. Status of current research in fish and wildlife. pp. 8-16. *In* Trans. Forty-Fourth N. Amer. Wildl. and Nat. Resour. Conf. March 24-28, 1979. Toronto, Ontario, Canada. Wildlife Management Institute. Washington, D.C.
10. National Science Board. 1977. Science indicators 1976. Nat. Sci. Board. National Science Foundation, Washington, D.C. 204 pp.
11. Bok, D. 1978. The critical role of basic scientific research. *In* Research universities and national interest: a report from fifteen university presidents. M. Cox, ed. Ford Foundation, Washington, D.C. 140 pp.
12. Smith, B. L. R., and J. J. Karlesky. 1977. *The State of Academic Science: the Universities in the Nation's Research Effort*. Change Magazine Press. Heldref Publ., Washington, D.C. 250 pp.
13. Society of American Foresters. 1978. Land classification series. Journal of Forestry. 76(10):633-696.
14. Nelson, D., G. A. Harris, and T. E. Hamilton. 1978. Land and resource classification—who cares? Journal of Forestry. 76(14):644-649.
15. Moen, A. N. 1973. *Wildlife Ecology*. W. H. Freeman and Company. San Francisco, Calif. 458 pp.
16. Pianka, E. R. 1974. *Evolutionary Ecology*. Harper and Row Publishers. New York, N.Y. 356 pp.
17. Krebs, C. J. 1972. *Ecology: The Experimental Analysis of Distribution and Abundance*. Harper and Row Publishers. New York, N.Y. 694 pp.
18. Sanderson, G. C., E. D. Ables, R. D. Sparrowe, J. R. Grieb, L. D. Harris, and A. N. Moen. 1979. Research needs in wildlife. pp. 26-35. *In* Trans. Forty-Fourth N. Amer. Wildl. and Nat. Resour. Conf. March 24-28, 1979. Toronto, Ontario, Canada. Wildlife Management Institute. Washington, D.C.
19. U.S. Fish and Wildlife Service. 1980. Habitat EvaluationProcedures (HEP) (ESM 102). Division of Ecological Services, Washington, D.C. (unpaged).
20. Holling, C. S., ed. 1978. *Adaptive and Environmental Assessment and Management*. John Wiley and Sons. New York, N.Y. 377 pp.
21. Kellert, S. R. 1979. Phase I—Public attitudes toward critical wildlife and natural habitat issues. Grant #14-16-0009-77-056. U.S. Dept. of Interior, U.S. Fish and Wildlife Service, Washington, D.C. 138 pp.
22. Hendee, J. C. 1972. A multiple-satisfaction approach to game management. Wildl. Soc. Bull. 2(3):104-113.
23. Trefethen, J. B. 1975. *An American Crusade for Wildlife*. Winchester Press and the Boone and Crockett Club. New York, N.Y. 409 pp.
24. U.S. Fish and Wildlife Service. 1980. Human use and economic evaluation (HUEE) (104 ESM). Division of Ecological Services, Washington, D.C. (unpaged).
25. Soileau, L. D., K. C. Smith, R. Hunter, C. E. Knight, D. K. Tabberer, and D. W. Hayne. 1973. Atchafalaya basin usage study. Louisiana Wildlife and Fisheries Commission Interim Report, July 1, 1971-June 30, 1972. Louisiana Wildlife and Fisheries Commission, Baton Rouge, La. 49 pp.
26. White, G. F. 1980. Environment. Science. 209(4452):183-190).
27. Thomas, J. W. 1979. Preface. pp iv-v *In* Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. J. W. Thomas, ed. USDA. Forest Service, Agric. Handbk. No. 553. U.S. Gov. Print. Off., Washington, D.C.

☆USGPO: 1982 — 559-092/0433